Rec'd PCT/PTO 19 MAY 2005 PCT/GB 2003/005030

The Patent Office

PATENTS • DESIGNS • COPYRIGHT • TRADE MARKS

REC'D 17 FEB 2004

WIPO PCT

INVESTOR IN PEOPLE

10/535459


The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ


I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

**PRIORITY DOCUMENT**

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Signed R. Mahoney

Dated 21 January 2004

BEST AVAILABLE COPY

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
D
19 NOV 2002
LONDON

The Patent Office

1/77

# Request for grant of a patent

*(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)*

The Patent Office

Cardiff Road
Newport
South Wales
NP9 1RH

1. Your reference

DB/REP02551/BEP

2. Patent application number 19 NOV 2002 0227016.3
*(The Patent Office will fill in this part)*

20NOV02 E764757-5 D00016
P01/7700 0.00-0227016.3

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

John Redding
Fleche Cottage
Old Town Hill
Lamberhurst, Kent TN3 8EN

08509689001
Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

DREDGING, SCOURING & EXCAVATION

5. Name of your agent *(if you have one)*

BROOKES BATCHELLOR

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

102-108 CLERKENWELL ROAD
LONDON
EC1M 5SA

Patents ADP number *(if you know it)*

08142291001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

| Country | Priority application number *(if you know it)* | Date of filing *(day / month / year)* |
|---|---|---|

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

| Number of earlier application | Date of filing *(day / month / year)* |
|---|---|

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
*a) any applicant named in part 3 is not an inventor, or*
*b) there is an inventor who is not named as an applicant, or*
*c) any named applicant is a corporate body.*
*See note (d))*

NO

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

| | |
|---|---|
| Continuation sheets of this form | -- |
| Description | 30 |
| Claim(s) | - |
| Abstract | - |
| Drawing(s) | 16 |

d 16 8

10. If you are also filing any of the following, state how many against each item.

| | |
|---|---|
| Priority documents | -- |
| Translations of priority documents | -- |
| Statement of inventorship and right to grant of a patent *(Patents Form 7/77)* | -- |
| Request for preliminary examination and search *(Patents Form 9/77)* | -- |
| Request for substantive examination *(Patents Form 10/77)* | -- |
| Any other documents *(please specify)* | -- |

11. I/We request the grant of a patent on the basis of this application.

Signature Brookes Batchelor Date 18 November 2002

12. Name and daytime telephone number of person to contact in the United Kingdom DAVID BAILEY 01892 510600

**Warning**

*After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.*

**Notes**

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

# DREDGING, SCOURING AND EXCAVATION

The present invention relates to underwater excavation of sediments and soils and simultaneous controlled movement of the excavated material. In particular, we will ~~describe apparatus for bulk excavation of sand, silt, clay and like materials from sea,~~ river, canal and lake beds, and near-bed movement of the excavated material in a controlled fashion. Controlled, in this sense, refers to direction and distance of movement and height of transport above the bed. The apparatus may also be used for removal of bio-fouling from vessels and marine structures.

A cutter-suction dredger is the most widely used apparatus for removing underwater sediments and soils. With this type of dredging apparatus, bed material is mechanically dis-aggregated by a rotating cutter, mounted in the suction head, while at the same time, a mixture of soil particles and water is drawn up through the suction pipe, as the suction head is trailed across the bed. The soil/water suspension is typically discharged into a hopper on the vessel, and once the hopper is full, the vessel steams to a suitable disposal site and the contents of the hopper are discharged. The disposal site may be at sea or on land, but is often many kilometres from the excavation site.

The present apparatus achieves dis-aggregation of the bed material by non-mechanical (hydro-dyanamic) means, and the excavated material is not brought onto the vessel, but rather is made to flow across the bed, away from the excavation site. Depending on the nature of the bed material and the requirements of the project, excavated material can be re-deposited locally (adjacent to the excavation site) or can be made to flow long distances (of the order of 100 metres) as a highly turbid near-bed suspension (turbidity current). Since turbidity currents tend to flow downhill, material excavated from shoal areas invariably ends up being deposited in deeper water. Such gravity-driven transport has particular advantages for navigation channel maintenance work, which is one of the primary uses of this equipment.

In its broadest sense, the present invention provides a fluid jet apparatus designed to create a swirling jet flow, which flow includes a system of one or more strong vortices.

~~In a first embodiment, the apparatus comprises a duct having a fluid inlet and a fluid~~ outlet, and a propeller mounted for co-axial rotation within the duct, wherein the propeller is adapted to produce the aforementioned swirling jet flow.

In a second embodiment, the apparatus comprises a fluid inlet for receipt of a flow of fluid and a fluid outlet and further comprises means adapted to produce a co-axial counter-rotating swirling jet flow from said outlet.

Typically, the apparatus is in the form of a nozzle attachable to a fluid supply. Typically, the fluid supply is generated by a large capacity, high-pressure pump.

In both cases, the fluid jet apparatus is capable of being mounted in a variety of ways such that the jet can be maintained at a controlled angle to, and height above, the bed.

Typically, the fluid is water.

It will be appreciated, by those skilled in the art, that the vortical content and fluid-dynamic character of the jet is largely determined:

- In the first embodiment, by the propeller; and in particular, by the number, pitch and shape of the blades; the speed of rotation of the propeller and by the flow of fluid through the duct, and
- In the second embodiment, by the way in which the counter-rotating coaxial swirling jet is generated and emitted from the nozzle; and the pressure driving the flow.

Additionally, it will be appreciated by those skilled in the art, that the processes involved with excavation and controlled movement of material by means of an impinging swirling jet, depend not only on the character of the jet itself, but also on how the jet interacts with the bed, how the excavated material is subsequently transported and how the whole process is regulated.

The above and other aspects of the present invention will now be described in further detail, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows, schematically, the principle features of a first embodiment of a fluid jet apparatus in accordance with the present invention;

Figure 2 illustrates various ways in which the embodiment of Figure 1 may be deployed from a floating vessel, including – a suspended Wing-mounted apparatus (Figure 2a), a suspended tank-mounted apparatus (Figure 2b), and a mechanical excavator vehicle-mounted apparatus (Figure 2c);

Figure 3 is a schematic illustration of the principle components of a free-stream jet formed by the embodiment of Figure 1;

Figure 4 is a diagrammatic representation of the impingement processes associated with near-bed jetting in sand with the embodiment of Figure 1;

Figure 5 is a diagrammatic representation of the impingement processes associated with near-bed jetting in clay with the embodiment of Figure 1;

Figure 6 shows means for regulating the behaviour of the jet from the embodiment of Figure 1, to ensure rapid excavation and long-distance movement of the material;

Figure 7 shows additional means for regulating the behaviour of the jet from the embodiment of Figure 1, in this case by changing the characteristics of the propeller and the propeller hub;

Figure 8 is an annotated sketch representation the jetting and transport mechanisms ~~invoked by use of the wide-angle diffuser;~~

Figure 9 shows, schematically, the principle features of a second embodiment of a fluid jet apparatus in accordance with the present invention;

Figure 10 illustrates various ways in which the embodiment of Figure 9 may be deployed from a floating vessel, including – a suspended manifold-mounted apparatus (Figure 10a), a T-shaped articulating manifold-mounted apparatus (Figure 10b), and a mechanical excavator vehicle manifold-mounted apparatus (Figure 10c); and

Figure 11 shows a way in which the embodiment of Figure 9 might be used for vessel cleaning.

Referring initially to Figure 1, there is illustrated a first embodiment of a fluid jet-producing apparatus of the present invention. The apparatus includes a duct 1 having an inlet 2 and an outlet nozzle 3. The inlet 2 is in the form of a bell-mouth 4 to facilitate uniform ingress of fluid into the duct. Mounted within the outlet nozzle of the duct is a propeller 5. Propeller 5 is mounted for rotation about an axis coaxial with the duct itself. Propeller 5 is caused to rotate by any suitable means. For example, rotation may be imparted to the propeller by means of an electric, hydraulic or pneumatic motor. As shown, an electric motor 6 is used, supported and spaced from the inner wall of the duct 1 by means of fins 7.

It will be observed from Figure 1 that outlet nozzle 3 is of smaller diameter than inlet 2 and that a constriction 8 provides a transition zone between the two areas. This arrangement ensures a uniform flow velocity through the annulus formed between the body of the motor 6 and the duct 1.

The propeller is multi-bladed and although Figure 1 shows a 4-bladed propeller, the actual number of blades may be 3 or more. The propeller has a large blade area ratio, which is defined as the sum of the area of the blades divided by the area of the propeller disc (or nozzle area). This is a primary requirement of the propeller design ~~with respect to thrust and cavitation criteria to which the blades will be subjected, but~~ it is also important for vortex development.

The blade outline is symmetrical (i.e. non-skewed) and the angle of pitch of each blade varies uniformly with the radius in such a way that there is an even loading on the blades from hub to tip. The type of propeller shown in Figure 1 is known as a Kaplan propeller, which typically has symmetrical aerofoil blade section geometry. This enables the propeller to be operated equally well when rotating in either direction.

The propeller is close fitting inside the outlet nozzle, which means that all the water passing through the duct is forced to pass through the propeller disc. In use, the propeller is made to rotate at high speed, typically in excess of 15 revolutions per second (900RPM).

For the type of seabed excavation work normally carried out with this first embodiment invention, the outlet nozzle duct would have a diameter of about 0.5 to 0.75m and the speed of rotation of the outer tips of the propeller blades would be in the region of 30 to 35m/sec. The duct would be pointed towards the bed, either vertically downwards or at an angle, and maintained at a controlled height above the bed.

For bio-foul removal, smaller-scale equipment, although with the same operating characteristics, would normally be used.

The apparatus of the first embodiment invention may be deployed in a number of ways, as illustrated in Figure 2.

The 'Wing Dredger' means of deployment (shown in Figure 2a) comprises a steel body 9, which may be in the form of an inverted wing profile. The inverted wing ~~profile provides stability in fast-moving currents. Attachment points 10 on the top~~ edge of the body 9 enable the body to be suspended from four wires 11. The wires provide the means for suspension of the body from a vessel-mounted A-frame or crane (not shown). By suitable paired adjustment of the length of the wires 11, the angle of forward/backward tilt (pitch) and sideways tilt (roll) of the body can be controlled. In the 'Wing Dredger' the ducts 12, which generate the jets, are in pairs and the duct intakes 13 are located outside and above the top of the body 9. In this paired duct arrangement, the propellers are contra-rotating to ensure torsional stability of the suspended body in the water.

The overall length of the ducts, as shown, is a function of the length of electric motors used to drive the propellers (see Figure 1). This is because a continuous flow of water is required across the length of the motors for cooling purposes.

In the arrangement shown in Figure 2b, the body 14 is in the form of a rectangular steel box or tank, which can, similarly, be suspended by wires from a vessel-mounted A-frame or crane. The body houses a single duct 15 mounted wholly within the body 14, such that the duct inlet is also enclosed by the body. Ingress of water into the body, and thereby into the duct, takes place through openings 16 on the underside of the body. Hinged louvre plates 17 positioned inside and across the openings 16 protect the body (and thereby the duct) from ingress of debris and also enable the flow of water into the body (and thereby the duct) to be adjusted.

It will be appreciated that in order to produce the tank arrangement shown in Figure 2b, duct 15 has to be significantly shorter than that shown in Figure 1 and Figure 2a. Accordingly, the motor used in the Figure 2b deployment means is of the hydraulic

type, the latter motors being more compact than the equivalent power electric motors. Reducing the length of the duct (and thereby the frictional surface area exposed to the flow) also means that a greater flow rate through the duct can be achieved for a given propeller rotation speed. Notwithstanding the reduction in length of motor and duct, in all other respects (i.e. shape of duct and design of the propeller) the Figure 2a and ~~Figure 2b deployment means ducts are identical.~~

A feature of the Figure 2b deployment means is that the first embodiment apparatus can be used either as a single-jet unit or in a multiple-jet arrangement. In the latter arrangement, several single-jet units can be coupled together in different configurations.

In the deployment means shown in Figure 2c, the duct 18 (which has the same duct/motor design as in Figure 2b deployment means) takes the form of an attachment to the backhoe arm of a long-reach excavator 19. For the purposes of over-water operation, the long-reach tracked excavator shown, is mounted on a spud barge 20. The long-reach excavator uses its hydraulic arm 21 to manipulate the duct 18, controlling the latter's position, height above the bed and angle of tilt. The excavator can also use the duct as a means for propelling and manoeuvring the spud barge, rather like an azimuth thruster. However, this is not the primary function of the duct.

The arrangement shown in Figure 2c is a particularly useful one for shallow-water excavation and for bio-foul removal operations, as the track-mounted excavator vehicle can be either land-based (i.e. operating from a dock or quay) or, as shown, supported over-water on a barge.

The fluid flow output from the said first embodiment jetting apparatus comprises a swirling jet of water containing an organised arrangement of coherent vortical flow structures (vortices). The jet is circular in outline, which is a direct consequence of the form of the duct and the outlet nozzle of the equipment.

The vortical flow structures within the jet comprise:

- A number of tip vortices (corresponding in number to the number of propeller blades). These collectively define the outer edge of the jet (or stream tube)
- A hub vortex, which defines the central axis of the jet
- ~~Initially, a multitude of vortex filaments organised into vortex sheets.~~

Providing a support medium for these structures and also the bulk of the fluid flow, is the main fluid mass of the jet, which has a component of swirl (tangential flow) around the central hub vortex. Swirl is imparted to the jet flow by the propeller and the swirl velocity increases progressively towards the central hub vortex. Because the main mass of the flow does not interact directly with the propeller, the flow is considered to be largely inviscid in character.

In order to promote a fuller understanding of the present first embodiment invention, the vortex structures and their role in the behaviour of the jet will now be described in further detail. For the purposes of this discussion, the jet is assumed to be emerging into still water (i.e. no relative movement between the apparatus and the ambient fluid).

The disposition of the vortex structures within the jet is shown diagrammatically in Figure 3. Note that for clarity, only one propeller blade and its corresponding tip vortex are shown. While Figure 3 relates more particularly to free-stream (i.e. non-ducted) propellers, the general features apply equally to the ducted propellers of the present first embodiment invention. Further details and the justification for the vortex structure arrangement in propeller jets (wakes) may be found in: Stella et al (*Stella A., Guy ., Di Felice F., and Elefante M. – Experimental Investigation of Propeller Wake Evolution by Means of LDV and Flow Visualisation, Journal of Ship Research, Vol 44, No 3 (2000), 155-169)* and in: Di Florio et al (*Di Florio D., Di Felice F., Romanon G.P., and Elefante M. – Propeller Wake Structure at Different Advance*

*Coefficients by means of PIV, Proceedings of PSFVIP - 3- March 18-21, 2001, Maui, Hawai, USA*).

Figure 3 shows also how the character of the vortices changes with distance from the nozzle in the case of a non-impinging jet (i.e. with the apparatus operating at a ~~significant height above the bed). It is appropriate to consider this situation first,~~ before looking at the situation of the jet impinging on the bed.

Tip vortices 22 diffused from the outer edge of each propeller blade are convected downstream with the jet flow. Collectively, the tip vortices define a stream tube 23, which initially has the same diameter as the outlet nozzle. Bearing in mind the close juxtaposition of the individual tip vortices, it is evident that stream tube 23 forms a more or less continuous sheath around the jet. The stream tube effectively separates the jet flow from the ambient fluid. There is thus little or no interaction between the jet and the ambient fluid, and the jet remains more or less as a straight-sided column. By contrast, in a normal turbulent round jet, interaction between the jet and the ambient fluid typically results in entrainment (assimilation) of ambient fluid and a progressive spreading of the jet.

Figure 3 shows that for approximately one propeller diameter downstream from the nozzle (marked A in Figure 3), the stream tube 23 contracts slightly, while at the same time the axial hub vortex 24 stretches. During this interval, the two-layered vortex sheet 25 and 26 shed from the trailing edge of each propeller blade (the upper and lower blade boundary layer wakes) becomes progressively absorbed (rolled up) into the two main vortex structures. The upper vortex sheet 25, rolls up into the blade tip vortex 22, while the lower vortex sheet 26, rolls up into the axial hub vortex 24. In this way, vorticity created on the propeller blade surface is conserved into the wake, augmenting the vorticity of the tip vortices and the central hub vortex.

After the peak of the roll-up process, the stream tube expands back to its original diameter.

At about four propeller diameters downstream (marked B in Figure 3), the tip vortices 22 start to exhibit instability and the stream tube begins to lose its circular form. This instability appears to be associated with a pulsating radial expansion and contraction of the jet as a whole. The hub vortex 24, however, remains coherent although ~~exhibiting a slight spiral flexure.~~

By ten propeller diameters (marked C in Figure 3) the tip vortices 22 have broken down completely, with only vortex remnants 27 remaining, and the stream tube envelope has effectively ceased to exist. The hub vortex 24, however, despite exhibiting a considerable amount of spiral flexure, still remains a recognisable structure.

Progress towards breakdown of the vortex structures, as described, depends on the propeller advance coefficient. Propeller advance coefficient (J) relates speed of water flow through the propeller disc to speed of rotation of the propeller:

$$J = V/nD$$

Where: V is speed of water flow through the propeller; n is propeller rotation speed and D is propeller diameter. A lower advance coefficient indicates less flow through the propeller for a given propeller rotation speed and implies more energy coupled from the propeller into the tip and hub vortices and also a greater amount of swirl compared to axial flow in the jet.

Breakdown of the vortex structures in the propeller jet (wake) takes place more quickly (i.e. over a shorter distance) as the advance coefficient is reduced.

Before considering impingement of the propeller jet on the bed, it is appropriate to describe more fully, certain aspects of vortex breakdown.

In view of the confining (albeit elastic) nature of stream tube 23, enclosing the axial hub vortex 24 and swirling jet flow (as depicted in Figure 3), a comparison can be made with earlier visualisation experiments on axial vortex breakdown induced in rigid tubes. The following references may be cited by way of example of such experiments: *Sarpkaya T. – On Stationary and Travelling Vortex Breakdowns, Jour. ~~Fluid Mech., Vol 45, (1971), 545-559; Faler J.H. and Leibovich S. – Disrupted States~~ of Vortex Flow and Vortex Breakdown, Physics of Fluids, Vol 20, No 9, (1977), 1385-1400; Escudier M.P., and Zehnder N. – Vortex-flow Regimes, Jour. Fluid Mech., Vol 115, (1982), 105-121.*

More recently, experiments coupled with numerical models have provided a more quantitive basis for the physical processes involved in vortex breakdown. The following references may be cited by way of example: *Marshall J.S. – The Effect of Axial Pressure Gradient on Axisymmetric and Helical Vortex Waves, Physics of Fluids, Vol A5, (3), (1993), 588-599; Marshall J.S. and Krishnamoorthy S. – On the Instantaneous Cutting of a Columnar Vortex with Non-zero Axial Flow, Jour. Fluid Mech. Vol 351, (1997), 41-74; Darmofal D.L., Khan R., Greitzer E.M. and Tan C.S. – Vortex Core Behaviour in Confined and Unconfined Geometries: a Quasi-One-Dimensional Model, Jour. Fluid Mech., Vol 449, (2001), 61-84.*

From the aforementioned studies, it has been established that above a certain threshold of axial velocity versus swirl velocity (i.e. Advance Coefficient, or reciprocal of Swirl Number ($1/\Omega$)) an axial vortex will behave in a super-critical fashion. A super-critical vortex flow is one in which wave-like disturbances on the vortex core can only propagate in a downstream direction. This is in contrast to a sub-critical vortex flow, in which wave-like disturbances on the vortex core can propagate in both directions.

As the axial velocity is reduced (or, conversely, the swirl velocity is increased) in a super-critical vortex, a point is reached at which the vortex becomes unstable (critical point) and will spontaneously revert to a sub-critical condition. This change from

super- to sub-critical often involves a large expansion of the vortex core (analogous to an hydraulic 'jump' in the case of free-surface liquids, or a 'shock' in the case of compressible fluids). However, other less dramatic forms of breakdown may also occur depending on the flow conditions.

The particular axial to swirl velocity ratio at which breakdown takes place is dependent on the specific axial velocity (or more particularly, Reynolds number) of the flow. In confined tube flows, breakdown will occur at higher relative values of swirl velocity for low values of axial velocity (i.e. low Reynolds number) and visa versa. In confined tube flows with high axial velocities (i.e. high Reynolds numbers), breakdown also tends to be of the spiral or 'S' type, as depicted in Figure 3.

In low axial velocity flows, breakdown typically involves a large expansion of the vortex core producing a 'bubble' type breakdown. In the experiments cited, a bubble type breakdown also invariably occurs when breakdown is induced in a wide-angle flared tube.

Apart from the nature of the upstream flow affecting the inception, form and position of the vortex breakdown in cylindrical tubes, downstream conditions can also have an influence. For instance, in the experiments reported by Sarpkaya (1971) partial blockage of the outlet of the tube in which a bubble type breakdown had formed, resulted in rapid upstream movement of the bubble to the point where it became attached to the end wall, forming a re-circulation cell.

Partial blockage of the outlet of the tube can be seen as equivalent to a reduction in axial velocity and the imposition of a pressure gradient on the flow in the tube.

The importance of an axial pressure gradient, in bringing a super-critical vortex to the point of breakdown, has also been highlighted in the aforementioned references by Marshall (1993), Marshall and Krishnamoorthy (1997) and Darmofal et al (2001). An

increase in pressure associated with a reduction in velocity is also the main reason why flared tubes are very effective at inducing a bubble-type breakdown.

Numerical modelling by Darmofal et al (2001) indicates that during breakdown expansion of the vortex core can effectively become unbounded. Whereas in rigid tubes unbounded expansion of a bubble-type breakdown is clearly not possible, as the tube would become completely blocked, in an elastic tube (such as the stream tube produced by the present first embodiment apparatus) or in an unconfined situation, much greater expansion of the vortex core is possible.

In the case of a propeller jet impinging upon the seabed, the distance from the bed, the angle of incidence of the jet and the nature of the bed material are all critical to the behaviour and character of the impinging jet.

Under typical operating conditions for near-bed jetting, the first embodiment fluid jet apparatus would not be operated at less than one propeller diameter from the bed. Two to three propeller diameters would be a typical minimum distance for jetting.
In the descriptions that follow it is assumed that no modification has been made to the duct outlet nozzle and that unrestricted flow is allowed on the inlet side.

Figure 4 illustrates what is believed to be the behaviour of the jet in the case of near-bed jetting in sand, and with the jet orientated orthogonal to the bed.

The mass of the flow is deflected radially in all directions across the bed, forming a so-called "wall jet" 27. Initially, at least, the upper surface of the wall jet flow remains bounded by the deflected stream tube 28, and so interaction with the ambient fluid is prevented.

The deflected stream tube is seen to act like the flared vortex tube in the aforementioned vortex breakdown experiments. Coupled with the blocking effect of

the bed, the axial jet flow in the impingement region is decelerated and experiences an adverse pressure gradient.

However, because of the relatively high permeability of the bed material, pressure leakage occurs into the bed, which reduces the severity of this adverse pressure ~~gradient. Similar pressure leakage is reported by Kobus et al (*Kobus H., Leister P.*~~ *and Westerich B. – Flow Field and Scouring Effects of Steady and Pulsating Jets Impinging on a Movable Bed, Jour. Hydraulic Research, Vol 17, No 3 (1979) 175-192*), in experiments on erosion in sand by normal turbulent round jets. A spiral or 'S' type breakdown 29 is thus thought to occur, or the jet remains essentially super-critical.

According to the aforementioned experiments by Marshall and Krinshnamoothy (1997), a super-critical jet is simply deflected by a rigid surface, in the same way as a normal turbulent round jet would be. Near-bed jetting behaviour in sand can thus be seen as similar to that with a normal turbulent round jet (op cite Kobus et al (1979) and *Ali K.H.M. and Lim S.Y. – Local Scour Caused by Submerged Wall Jets, Proc. Instn. Civ. Engnrs, Vol 81 Part 2, 1986, 607-645*).

Experience with the present apparatus in sand indicates that with the jet moving forward, a narrow trench is formed with the excavated material being deposited as levees on either side of the trench. The maximum distance that the excavated sand is moved is approximately 10-15m, which is consistent with a bed-load and/or low concentration suspension mode of transport by the deflected jet.

By tilting the jet, excavated material can be displaced preferentially in the direction that the jet is pointing. However, the distance of movement of the material is still, typically, less than 20m, indicating that the jet is continuing to behave as a normal turbulent round jet.

In the case of a bed formed of clay or similar low-permeability material (e.g. clayey sand or silt), pressure leakage into the bed cannot occur to the same extent.

The adverse pressure gradient caused by the bed and by the deflected stream tube is, therefore, more severe and the vortex breakdown effect is, consequentially, more marked. As shown in Figure 5a, below a stagnation point 30, a bubble-type breakdown develops in the form of a conical re-circulation cell 31 attached to the bed. In effect, this conical re-circulation cell is a distorted ring vortex. Consistent with the sense of rotation within the ring vortex, upward flow 32 takes place along the axis of the cell and the cell also rotates about its vertical axis due to the viscous coupling of swirl imparted from the deflected jet flow.

The cell partially blocks the deflected jet flow, resulting in further expansion of the stream tube, which itself leads to further growth of the cell. This self-fulfilling process results in a progressive enlargement of the cell, while maintaining an essentially conical form.

In Figure 5b the end stage of this conical re-circulation cell growth is shown, wherein the apex of the cell has grown upwards to meet the nose cone of the propeller 33. The sides 34 of the cell slope outwards at approximately $45^0$, which is the angle at which the stream tube 35 and the mass of the jet flow 36 are also defected. The base of the cell 37 (or impingement cone) is circular and has a diameter equivalent to approximately twice the height.

Although a rise in pressure occurs across the interface between the deflected jet flow and the cell, consistent with other types of 'shock', the overall pressure regime within the impingement cone is less than ambient. The impingement cone thus exerts a suction effect on the bed. This is in contrast to the impingement cone created by a normal turbulent jet, which exerts a net positive pressure on the bed.

Additionally, centripetal flow 38 occurs across the bed (i.e. towards the central axis of the re-circulation cell), which increases in velocity as it approaches the axis 39. The bed thus experiences a decreasing surface stagnation pressure gradient towards the axis.

~~Within the impingement cone footprint, bed material is drawn up into suspension by a~~ combination of:

- Scour by the overlying centripetal flow
- Suction, causing rapid upward flow of pore water through the bed sediment and thereby fluidisation of the bed material
- Suction, causing tensional failure of the bed material

The nature of the bed material will determine which particular type of entrainment process, or combination of entrainment processes, will take place.

However, operational experience with the first embodiment apparatus indicates that a wide range of low permeability sediments and soils can be excavated using this mechanism. Also, clayey sands and silts can be excavated much faster than clean sands as a result of the large excavation footprint and the bed fluidisation effect. Stiff clays (with a shear strength of 200kPa), not otherwise amenable to excavation by low-pressure turbulent jets, can also be excavated (albeit at a slower rate than unconsolidated sediment) because of the strong suction effect, inducing tensional failure in the material.

This suction-enhanced form of excavation is a particularly effective and efficient means of excavation, because most soils are weaker in tension than they are in either shear or compression.

An important feature of this particular impingement process is that excavated material, rather than being transported radially outwards, is initially drawn radially

inwards and then lofted by the rising axial flow 39 of the re-circulation cell. Once it reaches the apex of the cell, the bulk of the excavated material it is then flung out sideways due to centrifugal force to become entrained in the descending deflected jet flow. A portion of the material, however, tends to be re-circulated.

~~Because of:~~

1. the relatively high concentration of material entrained into the deflected jet flow increasing the latter's density relative to the ambient fluid;
2. the velocity of the deflected jet flow;
3. the shape of the impingement cone, in effect creating a $45^0$ ramp;
4. the continuing effect of the stream tube in preventing interaction between the deflected jet flow and the ambient fluid;

the impingement process, as described, thus represents the ideal conditions for the initiation of a high-speed, high concentration, poly-dispersed, turbidity current flow.

Such flows are able to move suspended sediment over long distances and in order to appreciate their significance to the operation of the present invention a brief description of turbidity current flows is appropriate.

Turbidity currents are a particular class of density flows. Density flows are produced where gravity acts upon a density difference between two fluids, causing the denser fluid to move. The denser fluid travels as a relatively thin layer across the bed, in effect wedging up the less dense fluid at its leading edge. With turbidity currents, the density difference is produced by particles maintained in suspension and convected by the moving fluid. Density flows can also be produced, for example, by concentrated salt solutions, temperature differences in air or water, dense suspension of particles in air (dust or snow).

In the case of turbidity currents the particles are in a transient state and will tend to sediment out from suspension. The distance over which particles can be transported in a turbidity current thus depends on the length of time that the particles can be buoyed up in the flow. The processes involved are complex, interactive and highly non-linear, and turbidity currents are in a continual state of flux as they adjust to internal and external factors.

To initiate a turbidity current, requires a particular set of circumstances, which can best be demonstrated by a simple kitchen sink experiment. This involves dropping a dense suspension of cornflour in water into a basin containing a few centimetres of clean water. It will be seen that the cornflour spreads out as a ring (ring vortex) across the bottom of the basin. The ring, which typically has a recumbent upper surface, is the head of the turbidity current, inside of which is a much thinner dispersed layer of cornflour, which is the body of the turbidity current.

If the cornflour is poured rather than dropped, it will be seen that the same ring vortex forms and is fed by the stream through the thin body layer. A steady stream of cornflour creates what is known as, a constant-flux turbidity current.

The three basic ingredients required to initiate a turbidity current are:

1. A means for generating a free vortex, in this case by creating shear between two fluid bodies
2. Sufficient density difference between the two fluid bodies
3. Sufficient momentum in the denser fluid body

Since the body of a constant-flux turbidity current carries the bulk of the suspended material, it plays a key role in terms of sediment transport. Amongst a wide range of factors, the following can be cited as important in achieving long-distance transport:

- Small particles (particularly silt and clay size particles) can be transported further because of their low settling velocity
- A high concentration, particularly of fine particles, will be transported further due to hindered settling (interaction between particles) and because of increased viscosity (less drag between current and overlying ambient fluid)
- A high concentration of clay particles will assist transport of coarser particles (silt and sand) because of the increased viscosity of the flow
- Elevated turbulence in the flow (high Reynolds stresses) will increase the distance of transport because turbulent eddies help to buoy up the suspended particles.

Many of these factors are discussed by Kneller and Buckee (*Kneller B. and Buckee C. – The Structure and Fluid Mechanics of Turbidity Currents: a review of some recent studies and their geological significance, Sedimentology, Vol 47 (Suppl. 1) (2000), 62-94*)

Apart from the distance of transport, the bed-hugging nature of turbidity current flows is particularly advantageous for environmental (water quality) reasons, since it minimises the extent to which sediment particles are carried upwards in suspension into the overlying water column.

It will be appreciated from the foregoing discussion that in the basic form of the first embodiment apparatus, as described, the bed itself plays a dominant rôle in determining the way that sediment/soil is excavated and moved.

Whilst this may have advantages in certain situations, it can also be a significant drawback. In particular, in sand, the inability to rapidly excavate over a large footprint area and move material over long distances poses a significant limitation. For this reason means have been devised that enable the excavation and sediment movement processes to be carried out in a more regulated fashion.

The particular equipment modifications to be described apply, primarily, to the short-duct-inside-a-steel-tank deployment means, shown in Figure 2b. However, they could equally well apply to other means for deploying the ducted propeller apparatus.

Each of the modification described may be used singly or in combination.

The first modification (previously mentioned) is designed to regulate the flow of water passing through the propeller duct, thereby controlling the axial to swirl velocity ratio of the jet. Hinged louvre plates 40, shown in Figure 6, are positioned over the primary intakes that lead to the propeller duct. The angle of these plates and thereby the gap between the plates determines the open area of each intake. A simple adjustable stop bar controls the extent to which the louvres can open when water is being drawn into the tank.

By increasing the amount of opening of the louvres, the inflow can be increased. This has the effect of increasing the propeller advance coefficient and thereby the axial to swirl velocity ratio. The jet thus becomes increasingly super-critical in character (i.e. less susceptible to breakdown) and so more like a normal turbulent round jet. Such a jet would be used, for instance, for pipeline trenching in sand; the excavated material being stockpiled on one side of the trench for later use in backfilling the trench.

Conversely, by reducing the amount of opening of the louvres, the inflow can be reduced. This has the effect of reducing the propeller advance coefficient and thereby the axial to swirl velocity ratio. The jet thus becomes more susceptible to breakdown. This would be advantageous when used in conjunction with the second modification means (the wide-angle diffuser attachment).

It will be appreciated that the overall size of the intakes shown in Figure 6, and the range of adjustment of the inflow by means of the louvre plates, covers the full range from maximum possible flow through the duct (louvres fully open) to minimum flow and cavitation on the propeller (louvres fully closed). It will be down to the

equipment operator to make the necessary adjustment to the louvre plates to achieve the desired duct inflow.

The second modification provides a means for forcing hub vortex breakdown, and also ensuring that the location of the breakdown is stabilised at a point just downstream of the propeller. In this way, the size of the impingement cone and thereby the size of the excavation footprint, become functions of the height at which the equipment is operated above the bed. The impingement cone, being "attached" to the equipment is also more stable and less likely to be affected by vessel speed, bed type, bed topography, etc.

The modification can be seen from Figure 6 to consist of a wide-angle diffuser 41 placed over the normal duct outlet nozzle. The diffuser can be easily attached (or detached) by means of a simple bolt-on flange 42.

The upper, attachment-end of the diffuser has parallel sides, which are coaxial with the propeller duct. The sides of the diffuser diverge smoothly downwards to form a bellmouth 43, which has an included angle of $90^0$ at its outer lip. The area of the outlet of the diffuser is twice that of the propeller duct outlet nozzle and the length of the diffuser is approximately the same as its inner diameter. The inner surface 44 of the diffuser is also, purposely, roughened (by means of sand-textured paint) in order to reduce the tendency of the expanding jet flow to separate.

The diffuser shape is specifically designed to force the stream tube to expand as it emerges from the propeller duct. This forced expansion of the stream tube creates the conditions necessary for ensuring breakdown of the hub vortex within the diffuser. The diffuser thus creates the same impingement cone effect as if the bed surface were impermeable (as indicated in Figure 5b).

Because breakdown of the hub vortex is no longer bed-dependent, rapid, large footprint area, excavation can be carried out also in high permeability materials (e.g.

sand). Equally important, movement of the excavated material, by means of turbidity current flow, can thus be carried out in sands as well as clays.

By tilting the jet slightly, so that the impingement cone becomes asymmetric, excavated material can be made to flow preferentially in the direction of tilt.

The diffuser attachment would typically be used where bulk movement of material is required, such as for navigation channel maintenance.

The third modification is intended to:

- Provide an additional/alternative means for reducing the axial flow velocity through the propeller duct, thereby decreasing the axial to swirl velocity ratio and bringing the flow closer to breakdown
- Increase the turbulence intensity within the swirling jet flow
- Provide additional protection from debris entering the propeller duct.

This modification comprises a simple wire mesh grid 45 placed over the entrance to the propeller duct. The location 46 of the grid is indicated in Figure 6.

It is well know that a wire mesh grid, placed within a flow stream, provides an effective means for generating small-scale turbulence (see for instance: *Pope S.B. – Turbulent Flows, Cambridge University Press, (2000), 158-161*). The turbulence generated by such a grid reduces the mean flow velocity, but does not significantly reduce the overall momentum flux of the flow.

The heightened level of turbulence created by this modification is intended to increase the sediment carrying capacity of the deflected jet flow. This is particularly important in the case of clean sand beds, especially where long-distance bulk movement of the material is required, since the capacity of a turbidity current to carry well-sorted sand

in suspension is a direct function of the level of turbulence (or turbulent kinetic energy) within the flow.

Figure 7 shows additional means for regulating the behaviour of the jet. In Figure 7a and 7b two alternative, interchangeable, hub designs are shown. The conical design shown in Figure 7a would be used where a super-critical jet was required, for instance, for narrow trenching operations, since the design promotes axial flow within the jet. The flared design shown in Figure 7b would be used where breakdown of the hub vortex to form a re-circulation cell was required, and might be used in conjunction with the wide angle diffuser attachment, for bulk excavation and long distance movement of material.

In Figure 7c one of a number of alternative propeller designs is shown. In this case, the design is intended to produce a high axial velocity jet that would be used for cutting deep narrow trenches.

Figure 8 illustrates what are envisaged to be the processes involved during bed impingement under fully developed re-circulation conditions. In this case, re-circulation is achieved by means of the wide-angle diffuser fitted to the first embodiment apparatus. However, the same effect could be achieved with the first embodiment apparatus, without the diffuser, if the bed were composed of impermeable material. Note also that the same effect is envisaged to occur with the second embodiment apparatus.

Figure 8a shows the jet operated orthogonal to the bed, in which case the impingement processes are axi-symmetric and the impingement footprint is circular. Figure 8b shows the jet tilted at an angle of about $15^0$. In this case, the impingement cone becomes asymmetric and more of the deflected jet (and thereby the excavated material) is displaced in the direction of tilt. The impingement footprint also becomes egg-shaped with the expanded portion extending in the downstream direction. By analogy with helicopters operating in ground effect (see: *Griffiths D.A. and Leishman*

*J.G. – A Study of Dual-Rotor Interference and Ground Effect Using a Free-Vortex Wake Model. Presented at the 58th Forum and Technology Display of the American Helicopter Society International. Montreal, June 11-13, 2002*) and transiting into forward flight, it is envisaged that the tip vortices forming the deflected stream tube tend to roll up into a bundle on the upstream side, reflecting (or reinforcing) the fact that there is a diminished amount of flow in this direction.

It will be evident from Figure 8b that any further substantial decrease in the angle of incidence of the jet with the bed, and the re-circulation effect would cease to be operative. The excavation and transport processes, as described, would also cease.

Referring to Figure 9a, there is illustrated in section a second embodiment of a fluid jet-producing apparatus of the present invention. Depending on the particular application, the size of the apparatus used may be several times larger or several times smaller than that shown in Figure 9a. The apparatus comprises a counter-rotating co-axial swirl-generating nozzle 47, which typically will be attached to a source of high-pressure fluid (not shown) by means of a flange 48. The flange 48 has holes 49 around its periphery, to enable it to be bolted to a casing (manifold) containing the supply of high-pressure fluid.

Mounted centrally and forming part of the flange is a wide-angle diffuser 50, which has sides 51 that slope outwards at $45^0$; opposite sloping sides of the diffuser thus form an included angle of $90^0$. Extending inwards from the diffuser are parallel sides 52 that form the inside diameter of the flange. Both the inner lip 53 of the flange and the transition 54 from side 52 to side 51 are radiused.

Attached to the flange 48 by a series of bolts 55 is a circular profiled centre body 56. While attached to centre body 56 by means of a series of bolts 57 is a circular dished top plate 58. It will be seen from Figure 8a that although flange 48, centre body 56 and top plate 58 are firmly attached one to another, they are separated by spacers 59, which create two separate passageways through the nozzle. The passageways are

indicated by arrows, which show the direction of axial fluid flow through the nozzle. Upper passageway 60 slopes inwards towards a central chamber 61, created by the curved inner surfaces 62 of centre body 56 and the inverted domed surface of top plate 58. Lower passageway 63 is initially horizontal but is turned through $90^0$ by virtue of curvature of centre body 56 and the curved lip 53 and side 52 of the flange 48.

Both the central chamber 61 and lower passageway 63 have downward coaxial openings into the diffuser 50. Septum 64, forming part of centre body 56, separates the two openings, which become coincident at the circular knife-edge 65 formed by the intersection of curved surface 62 and parallel sided surface 66. The plane of curvature of curved surface 62 is coincident with the inner sloping surface of the diffuser 50.

Reference to Figure 9b shows that spacers 59 are in fact vane elements, common to both lower and upper passageways. Orientated as shown in Figure 9b, the vane elements have an elliptically rounded outer projection and a wedge-shaped inner projection extending to a knife-edge. Vane elements 59 are held in place by bolts 55 and 57 that pass vertically through each element. Although Figure 9b shows 12 vane elements in each passageway, the number is not important. What is important is that the vane elements are disposed so that they direct high-pressure flow into the nozzle, tangentially to the vertical axis of the nozzle. Both the angle of the vane elements (and thereby the tangency of the flow) and the gap between the vane elements (and thereby the rate of flow through each passageway) can be adjusted. Although all 12 vane elements in each passageway would typically be adjusted as a group, the angle of tangency/gap between the vane elements need not be the same in the two passageways.

It should be noted, however, that for the particular way in which nozzle is to be operated, the vane elements in the two passageways would be orientated in opposite

directions. This is so that the flow through the two passageways develops a counter-rotational swirl.

The nozzle is designed to work as follows. When the nozzle is connected to a source of high-pressure fluid, fluid enters both the upper and lower passageways and is made to rotate by virtue of the vane elements in each passageway. Rotating fluid enters centre chamber 61 where is turned into a vertical stream. This vertical stream has a swirl velocity, which increases towards the central axis, where an axial vortex core develops. The slope of the upper passageway 60 and the disposition of the vane elements 59 within this passageway are such that the axial velocity of the flow entering chamber 61 exceeds the swirl velocity for the particular flow conditions in the nozzle. The axial vortex formed in chamber 61 is thus a super-critical vortex (as previously discussed) although not excessively so.

As the swirling flow passes downwards, beyond the constriction of chamber 61, it is forced to expand by the outward curvature of the lower part of the chamber. Chamber 61 thus acts like a venturi. As the flow expands it experiences an axial adverse pressure gradient. The axial vortex is forced into a critical condition and the resulting breakdown causes a stagnation point to develop in the outer throat of chamber 61 and a bubble-type breakdown structure to develop in the diffuser. The sides of the breakdown bubble slope outwards at $45^0$, paralleling the sloping sides 50 of the diffuser.

The bubble partially blocks the nozzle and so deflects the mass of the flow passing through chamber 61 over the surface of the bubble. The outer part of this deflected flow interacts with the counter-swirling flow, which emerges from the annulus of the lower passageway 63. This latter flow is also deflected.

Pronounced flow shear interaction occurs along the interface between the two counter-rotating flow streams resulting in the formation of vortex elements, which collectively form a vortex sheet separating the two flows. This vortex sheet can be

seen as the equivalent of the deflected stream tube in the case of the aforementioned first embodiment apparatus.

The breakdown bubble naturally tends to form into a re-circulation ring vortex structure, the apex of which remains rooted inside the nozzle outlet.

---

If the nozzle is placed adjacent to a solid surface, the ring vortex becomes distorted into a circular cone, triangular in section, as indicated in Figure 8. Note that this impingement effect is identical to that obtained with the first embodiment apparatus jetting in clay or with the wide-angle diffuser attachment fitted. Likewise, bed impingement results in material being lifted from the bed, drawn inwards and upwards along the axis of the re-circulation cell and then discharged into the deflected flow stream. Transport of the excavated material by the deflected flow stream, in the form of a turbidity current flow, is also a key feature of this second embodiment apparatus. The bed impingement processes are generally as visualised in Figure 8.

It will be appreciated by those experienced in the art that the basic form of the second embodiment apparatus is similar to that of a swirl cup combustor, as used in advanced gas turbine engines. However, the second embodiment apparatus has no connection with combustion or with gas turbine engines. It will also be appreciated by those experienced in the art of underwater jetting that the energy of a high-pressure jet dissipates very rapidly with distance from the nozzle and that water can only be raised to high pressure (20bar) economically in relatively small quantities.

Accordingly, the means for deployment of the second embodiment apparatus involves a multitude of nozzles held relatively close (typically less than 1m) to the bed. In Figure 10 and Figure 11 a common in-line manifold arrangement for supporting the nozzles is shown, with the nozzles disposed at intervals such that the bed impingement footprint of each nozzle overlaps slightly with that of the adjacent nozzles. The general form of construction of the manifold (common to each of the means of deployment discussed) will be described by reference to Figure 10a.

In Figure 10a, the manifold 67 is supported on wires 68 attached to the two ends of the manifold. The attachment points 69 allow adjustment of the angle of forward/ backward tilt of the line of nozzles relative to the bed. Raising or lowering of either wire also allows the manifold to be tilted sideways. The manifold is intended to be supported from a vessel-mounted A-frame or crane (not shown).

The manifold 67 comprises an I-section steel beam 70 in which circular openings and bolt holes are formed at equal intervals along its length for attachment of the individual nozzles 71. A half section steel tube 72 is welded to the top of the I-beam, as shown, to form an enclosed channel through which the high-pressure fluid can circulated before entering the nozzles. The two ends of the channel are blanked off by means of plates 73.

The down-stands 74 on the I-beam provide protective skirts to prevent mechanical damage to the exposed part of the nozzles.

One or more inlet pipes 75 formed on the top of the manifold provide for ingress of high-pressure fluid. The latter may be generated on the vessel and conveyed to the manifold through a flexible hose or, alternatively and as indicated in Figure 10a, the high-pressure fluid may be generated on the manifold by means of two multi-stage electric submersible pumps 76. The arrangement shown in Figure 10a would be used, for instance, for deeper water operation, since it is more efficient to convey electrical power to pumps, rather than high pressure fluid from pumps, over long distances.

The pumps 76 are placed motor end to motor end with a common shroud pipe 77 extending over the pump intakes 78. This is to provide a cooling flow of water over the pump motors. A length of Johnson (or similar) well screen 79, forming part of the shroud, provides additional protection against ingress of oversize material into the pumps.

In Figure 10b essentially the same manifold construction is used, but the manifold 80 forms the cross member of a T-shaped pipework arrangement, which comprises a downpipe 81 and a swivel inlet pipe arrangement 82. The latter conveys the high-pressure water from the downpipe to the manifold, while allowing the manifold to be rotated about its long axis. Rotation of the manifold is achieved by means of the ~~hydraulic ram 83, whose extension can be linked directly to the angle of the~~ downpipe.. Controlled rotation of the manifold means that the angle of the line of nozzles relative to the bed can be maintained constant regardless of the water depth.

A similar (but passive) swivel pipe arrangement 84 is used at the upper end, which allows articulation of the downpipe and connects the vessel-mounted pumps (not shown) to the downpipe. The vessel as shown, is a twin-hulled barge, with an A-frame 85 that can be used to raise and lower the manifold by means of a winch (not shown) and maintain it at the correct height off the bottom.

In Figure 10c, a similar but smaller-scale version of the manifold is shown. In this case, the manifold 86 is mounted on the backhoe arm 87 of a mechanical excavator 88 and the high-pressure fluid is supplied via a flexible hose 89. The tracked excavator would be operated from a barge or pontoon, or off the side of a jetty or dock, as in the case of Figure 10c.

A similar arrangement to that shown in Figure 10c might also be used for cleaning ships' hulls. Although in this case, the two ends of the manifold would be fitted with wheels designed to maintain the manifold and the nozzles at the optimum distance from the hull. Also, the nozzles would be operated normal to the hull surface. The optimum distance would be a balance between maximum cleaning efficiency and the self-induced residual suction effect that would be used to hold the manifold firmly against the hull.

An alternative deployment arrangement for cleaning ships' hulls is shown in Figure 11. In this arrangement, there are pairs of wheel 90a and 90b at either end of the

manifold 91, which are supported on struts 92 in such a way that they maintain the nozzles at a fixed distance from, and normal to, the hull. One of the wheels in each pair is a drive wheel, and in the case of the design shown in Figure 11, an enclosed drive shaft connects this drive wheel to a hydraulic motor and gearbox 93 housed in a compartment at each end of the manifold. The two drive motors can be operated together or independently, so that the whole machine can be moved forwards or backwards, or steered right or left.

High-pressure fluid is supplied to the nozzles via a flexible hose 94, loosely bundled to which are the hydraulic hoses 95 to power the drive motors. This machine is of relatively light-weight construction, being designed to adhere to the hull purely by virtue of the suction created by the nozzles. It is also designed to be remotely operated from a support vessel (not shown), which provides the source of high-pressure fluid for the nozzles and also hydraulic power for the drive motors.

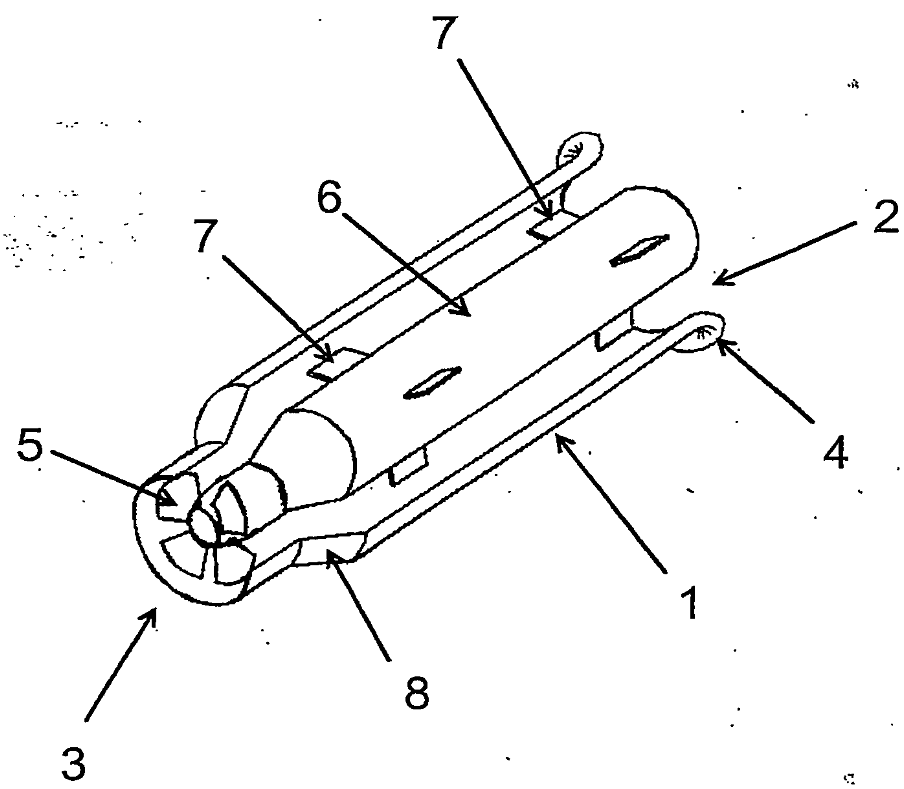



Figure 1

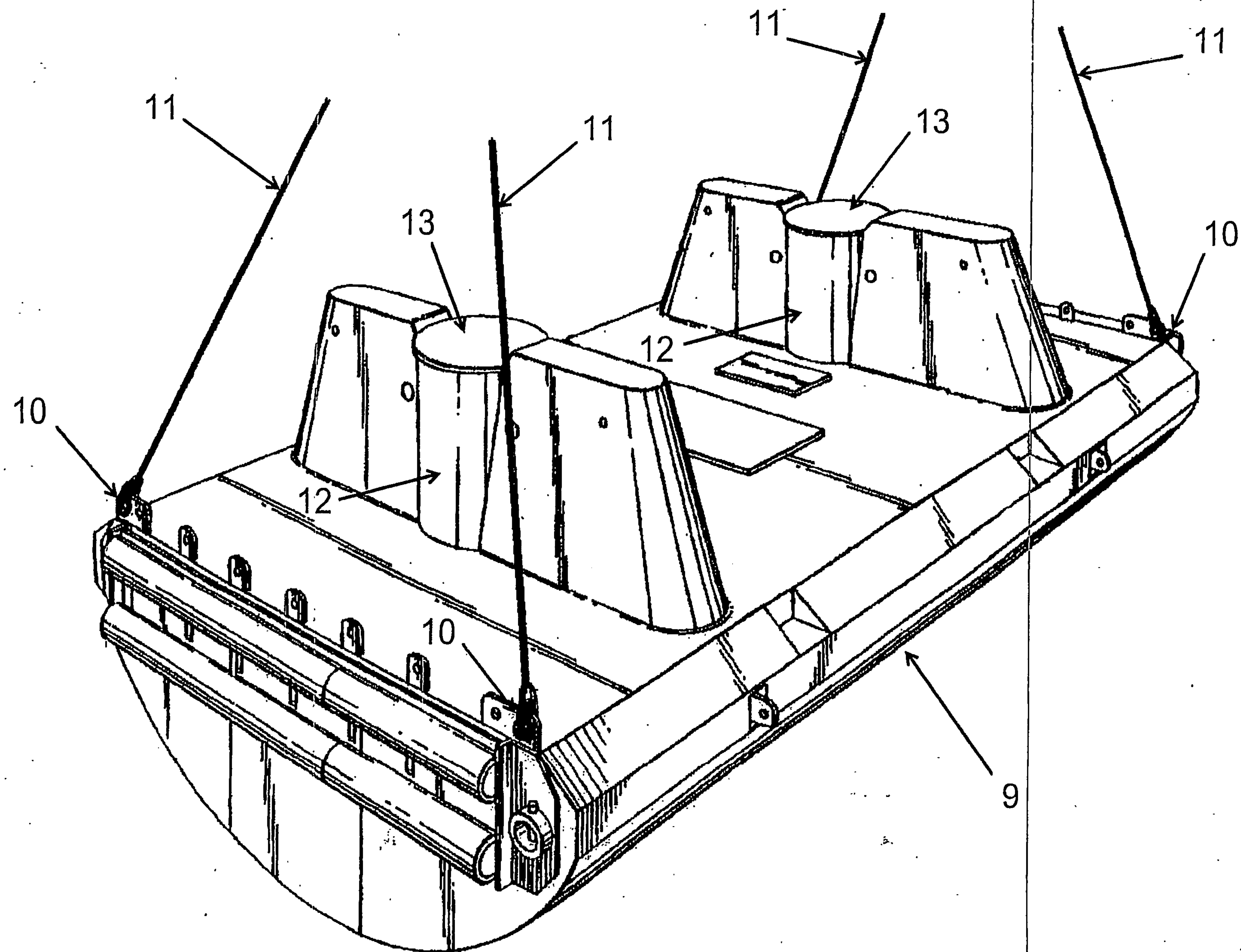



Figure 2a

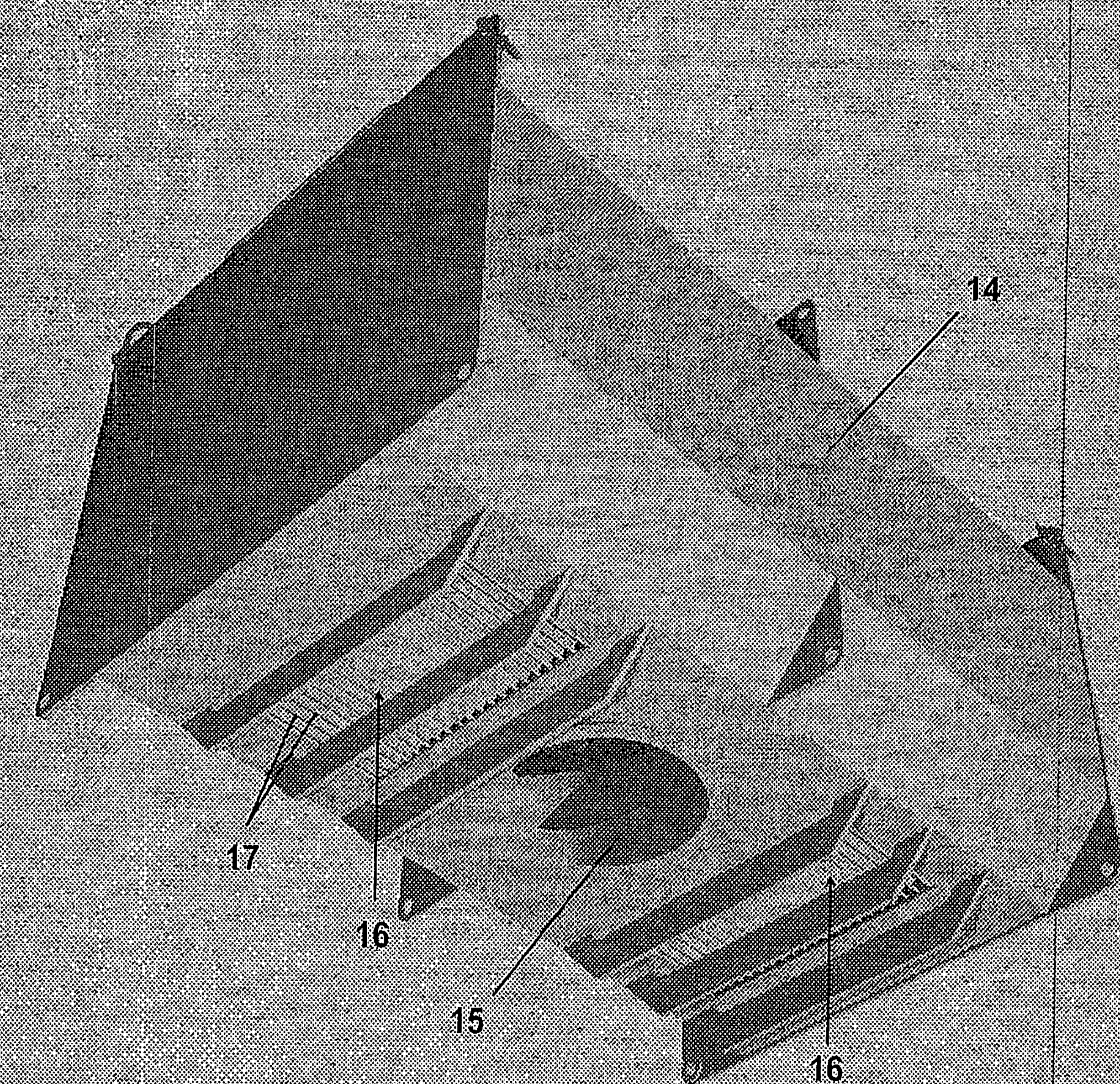



Figure 2b

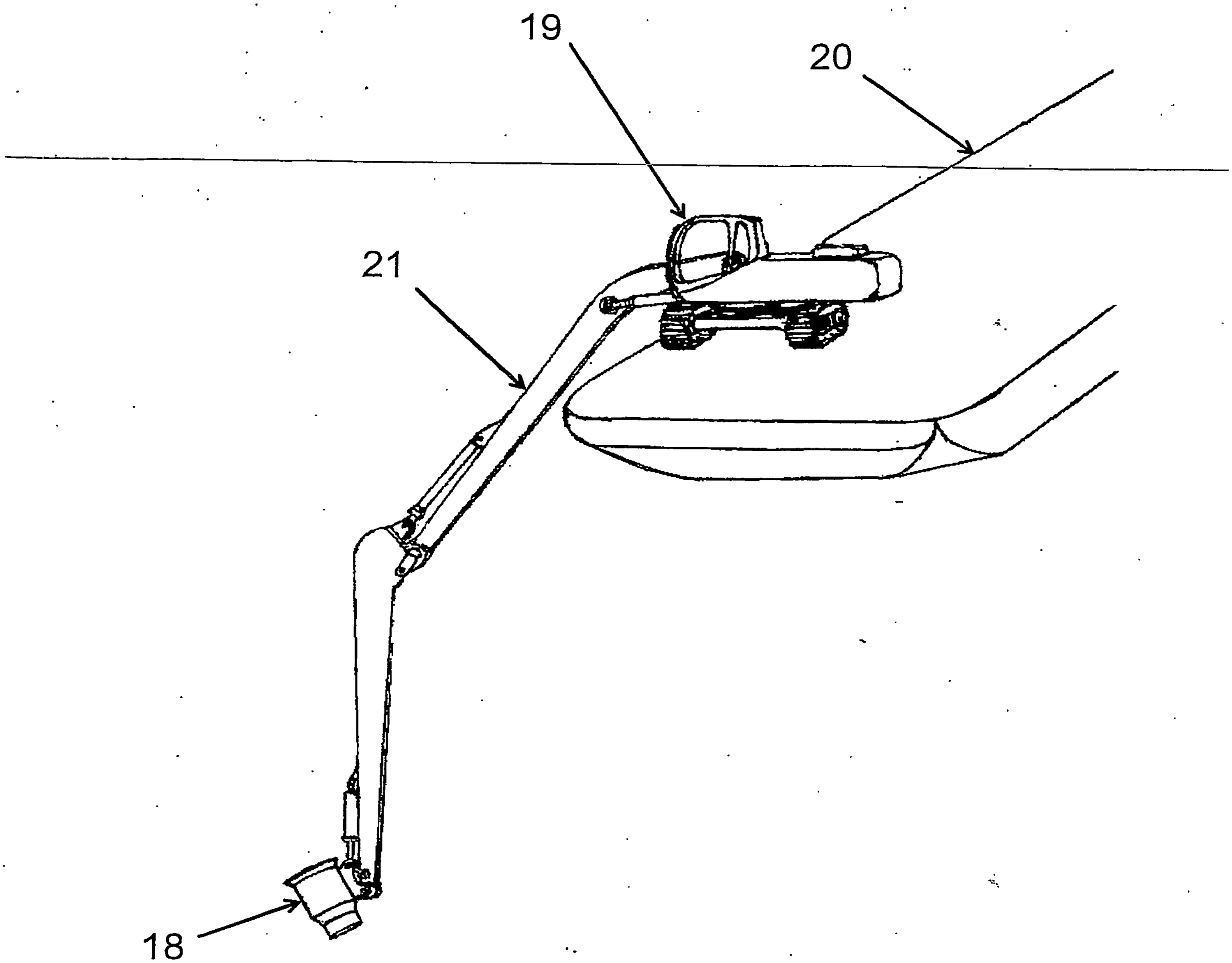



Figure 2c

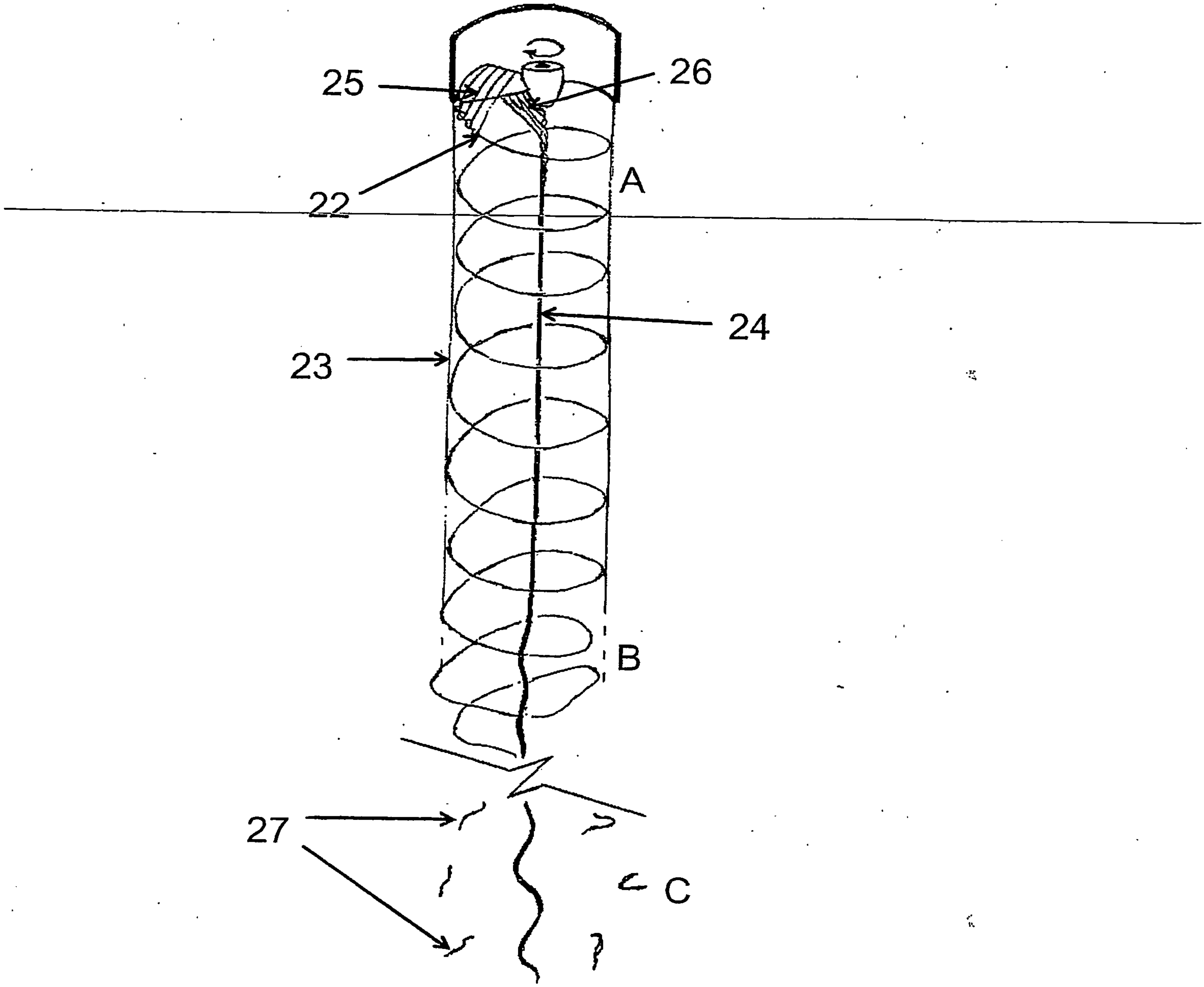



Figure 3

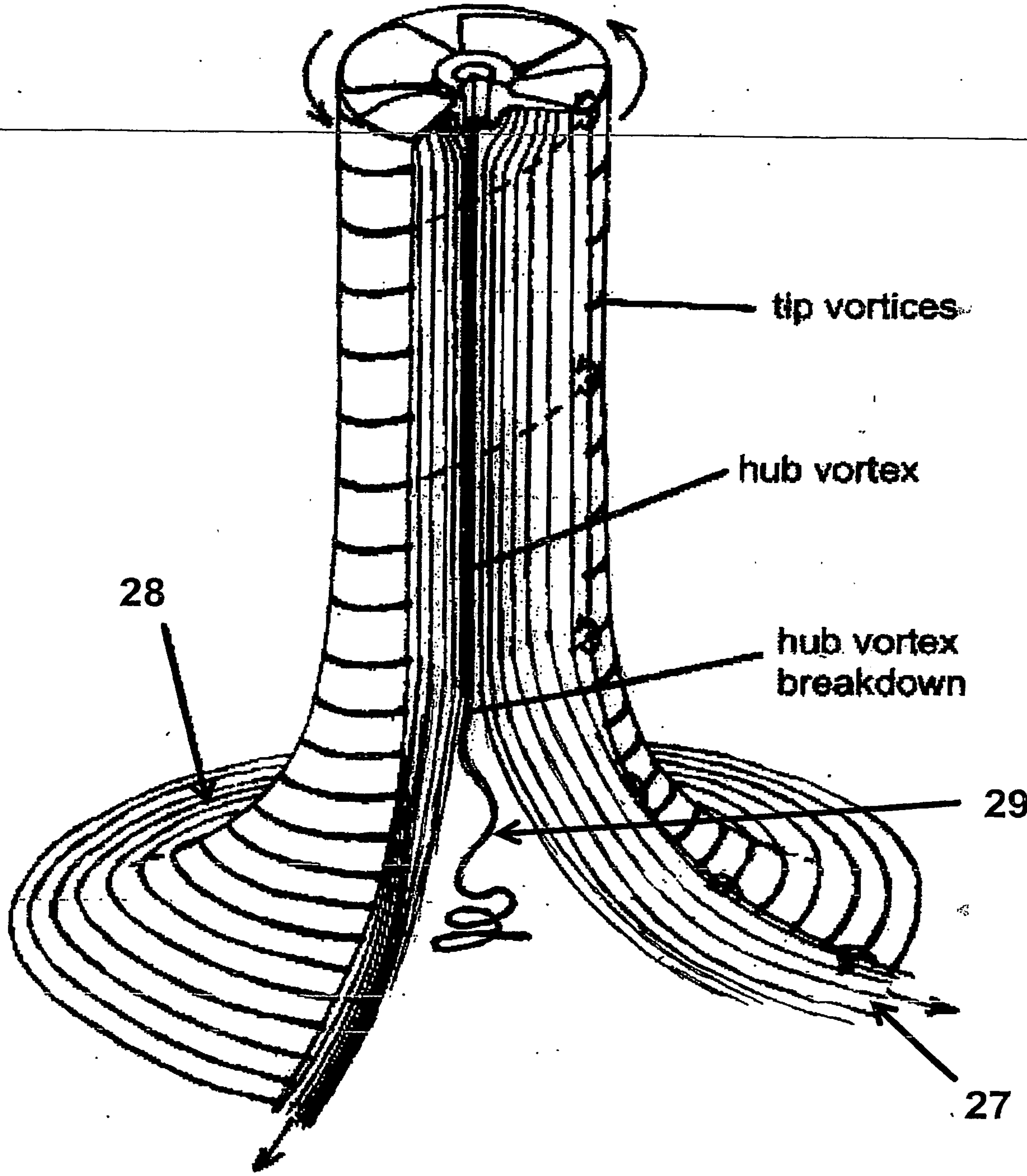
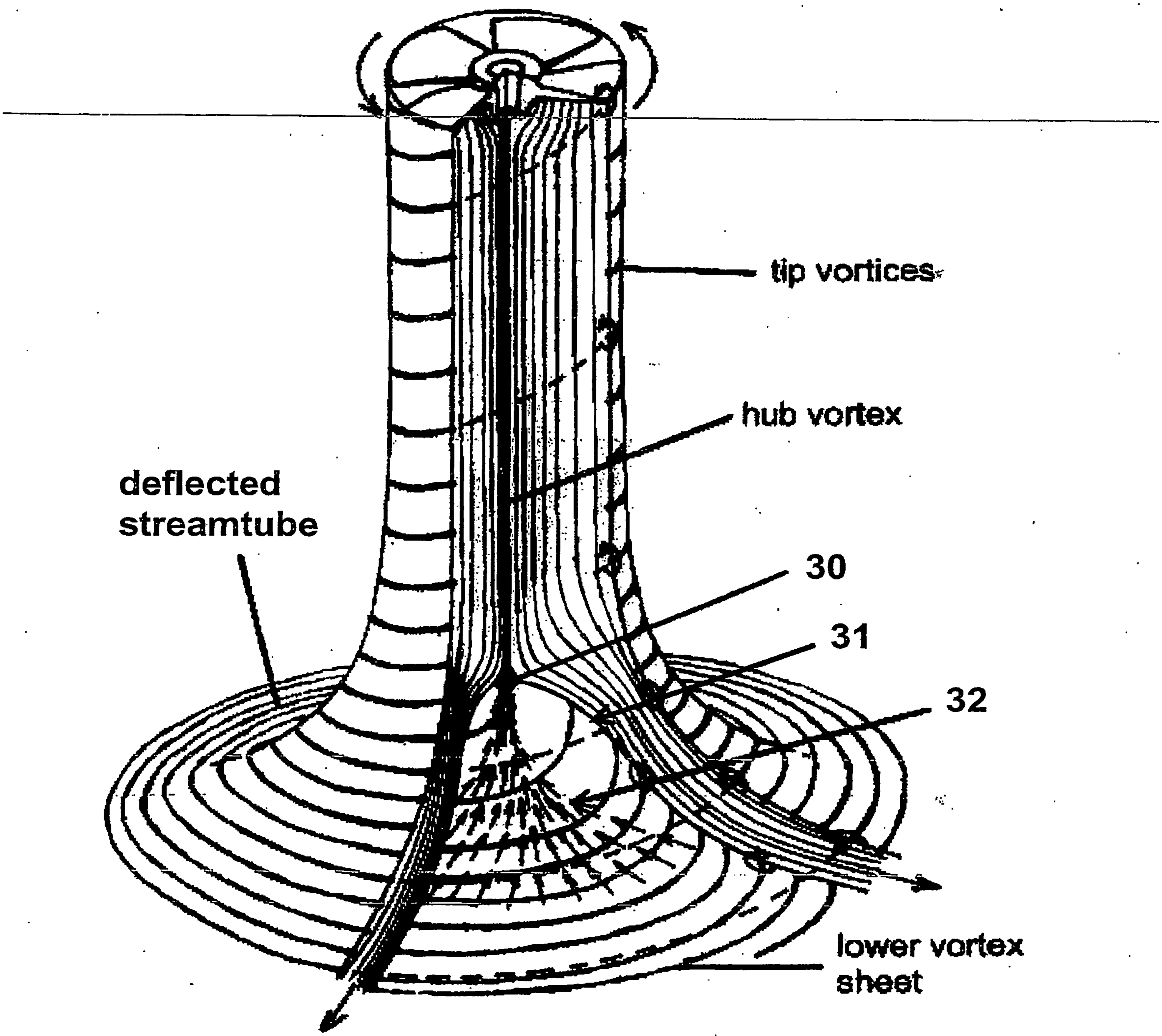



Figure 4



tip vortices
hub vortex
deflected
streamtube
30
31
32
lower vortex
sheet


Figure 5a

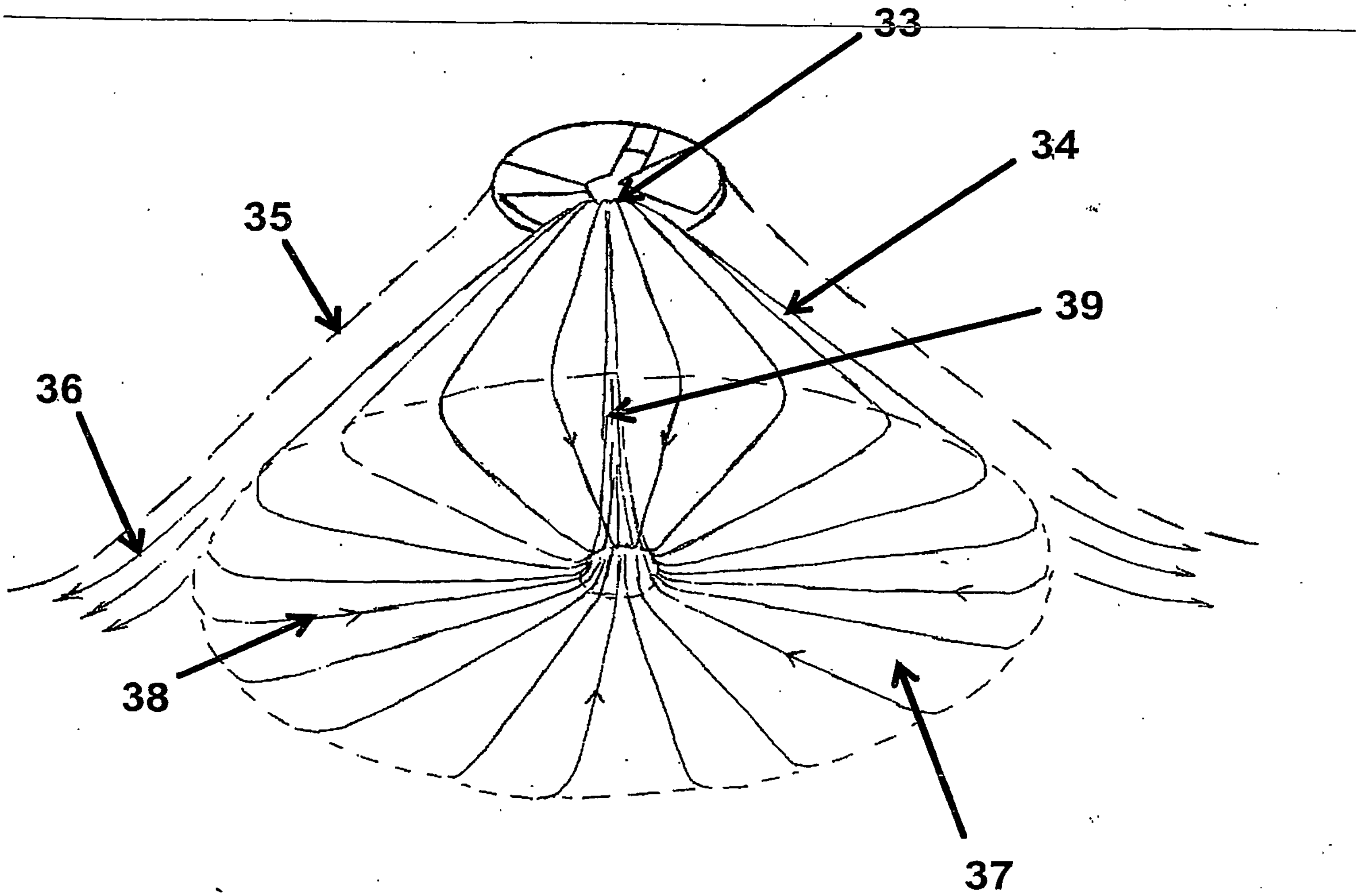



Figure 5b

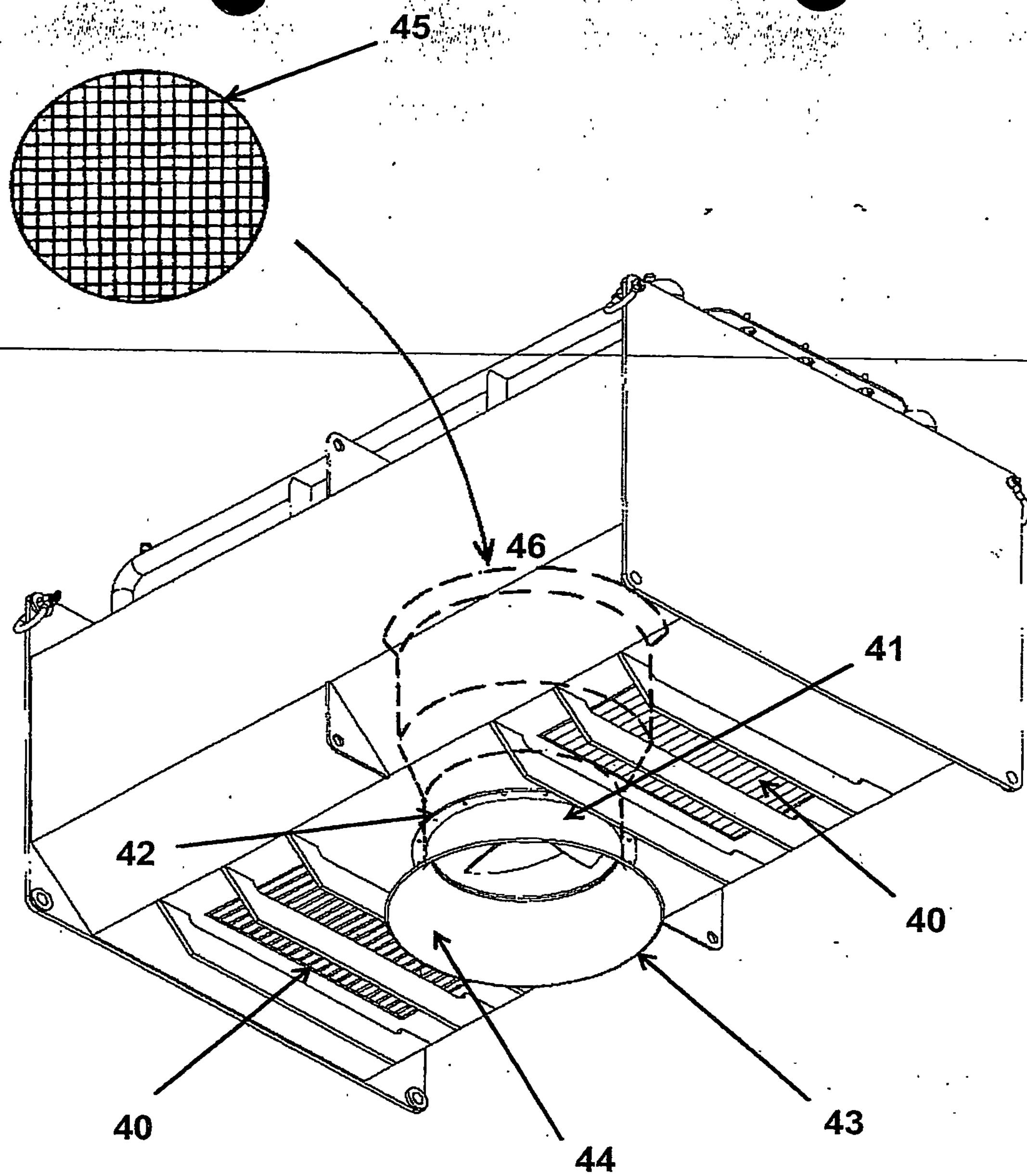
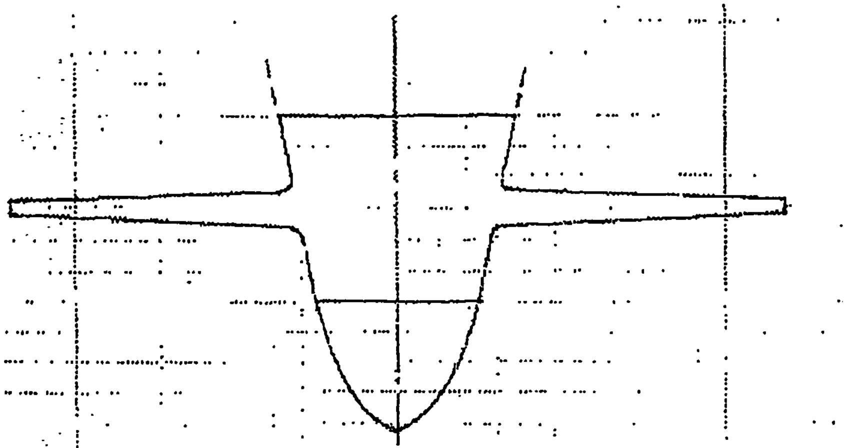
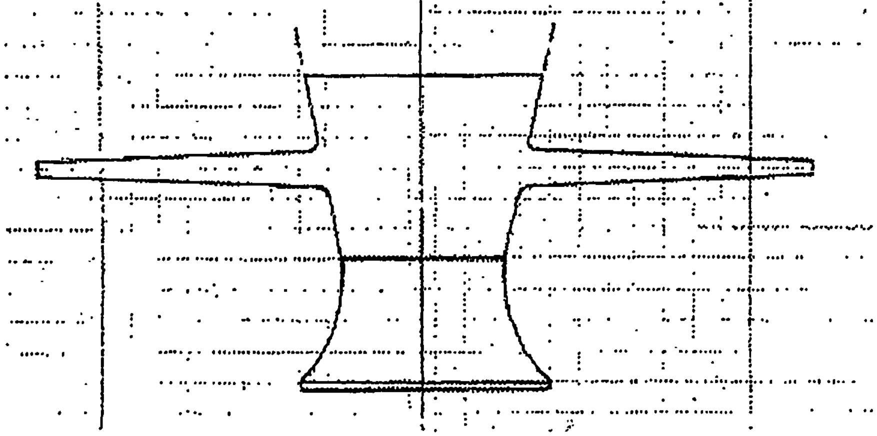


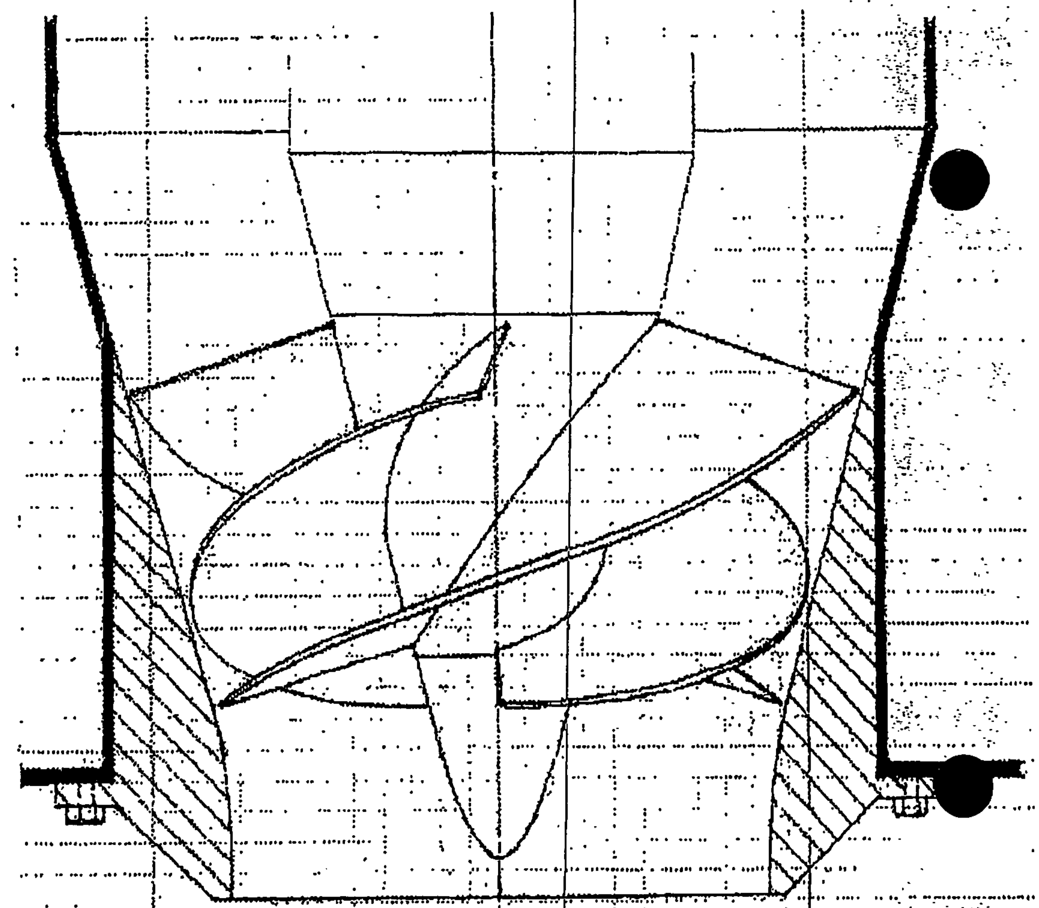

Figure 6



a. conical hub



b. flared hub



c. alternative propeller design

Figure 7

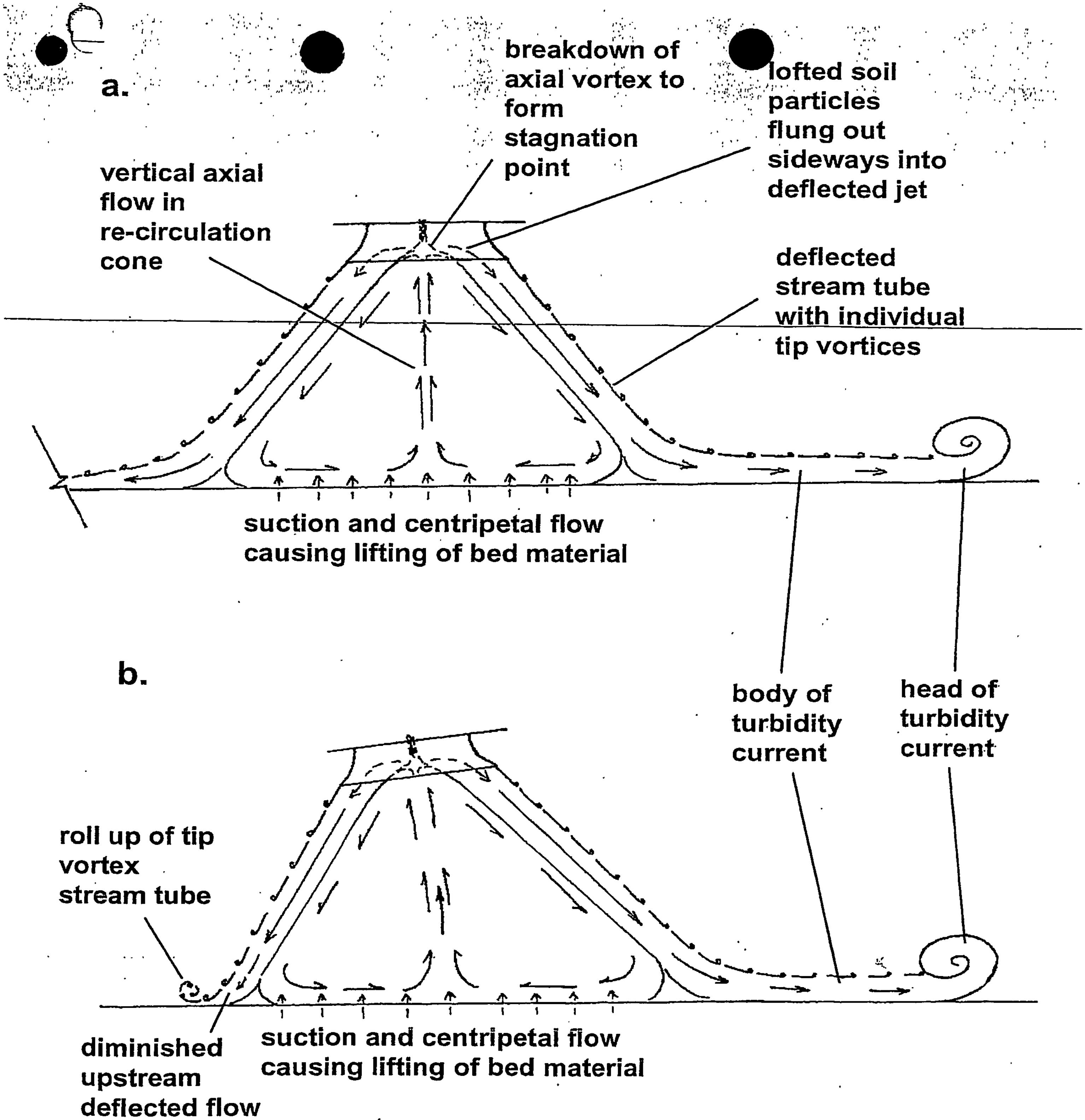
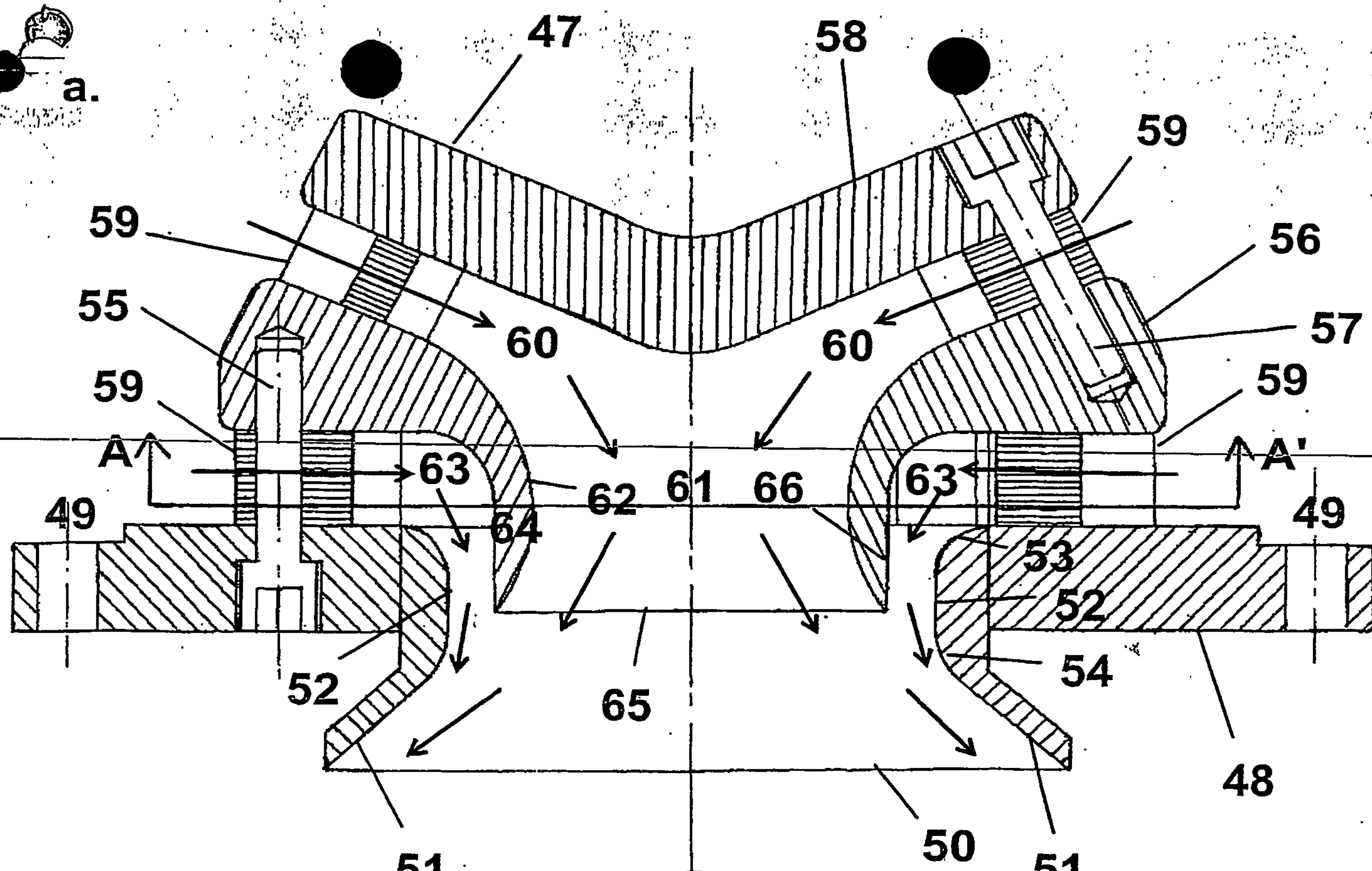

a.
breakdown of axial vortex to form stagnation point
lofted soil particles flung out sideways into deflected jet
vertical axial flow in re-circulation cone
deflected stream tube with individual tip vortices
suction and centripetal flow causing lifting of bed material
b.
body of turbidity current
head of turbidity current
roll up of tip vortex stream tube
diminished upstream deflected flow
suction and centripetal flow causing lifting of bed material

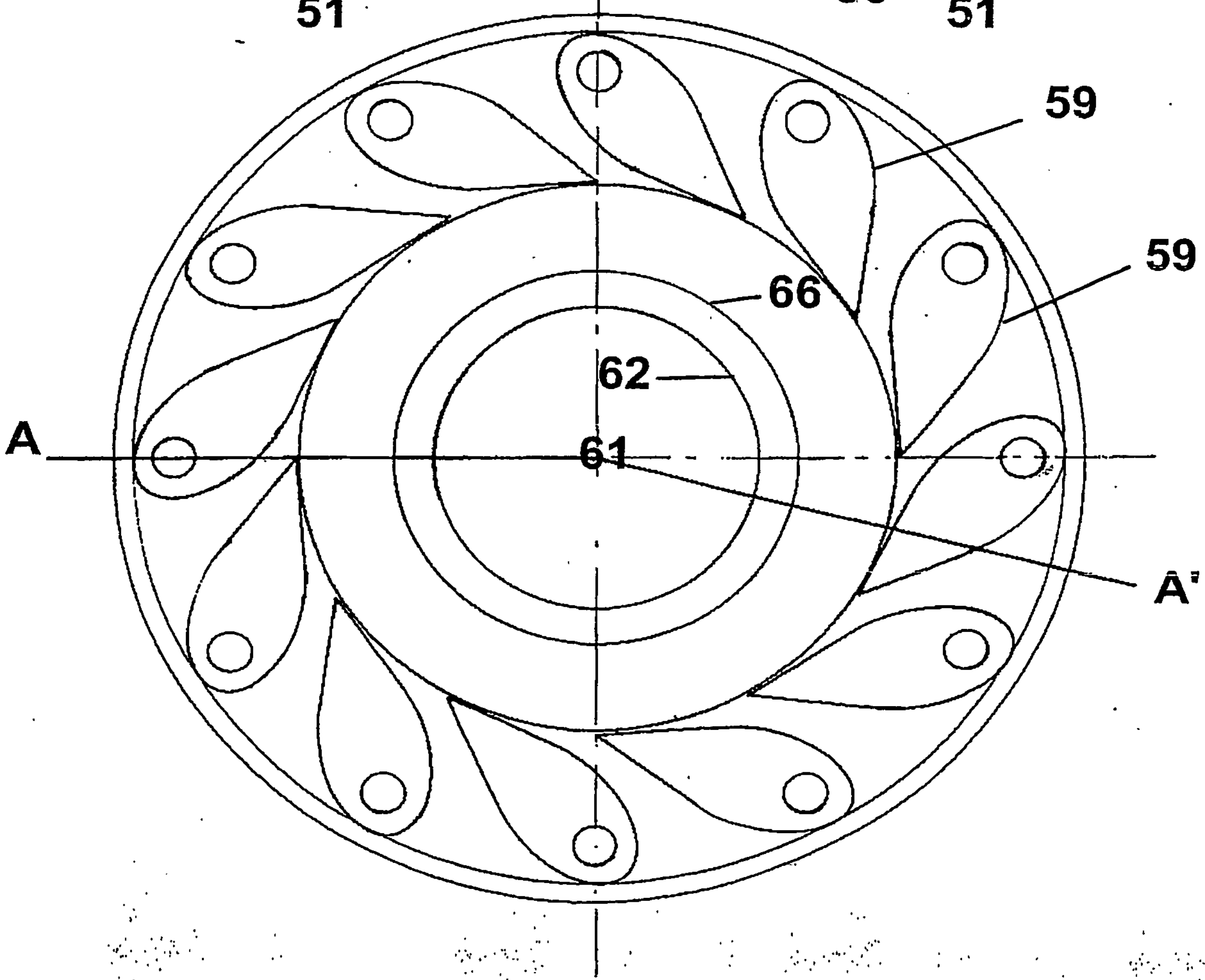
Figure 8

a.



47
58
59
59
56
55
60
60
57
59
59
A
A'
63
63
62
61
66
49
49
64
53
52
52
54
52
65
48
51
50
51


b.



59
59
66
62
A
61
A'


Figure 9

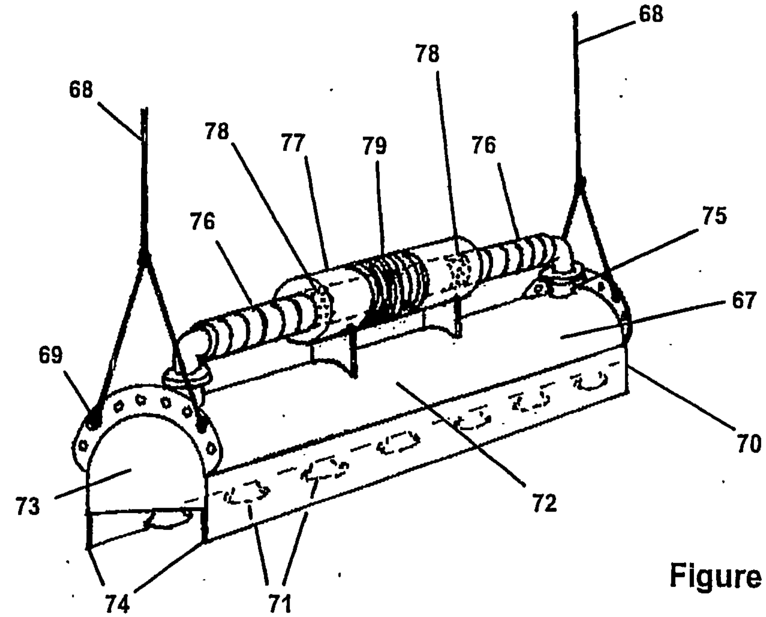



Figure 10a

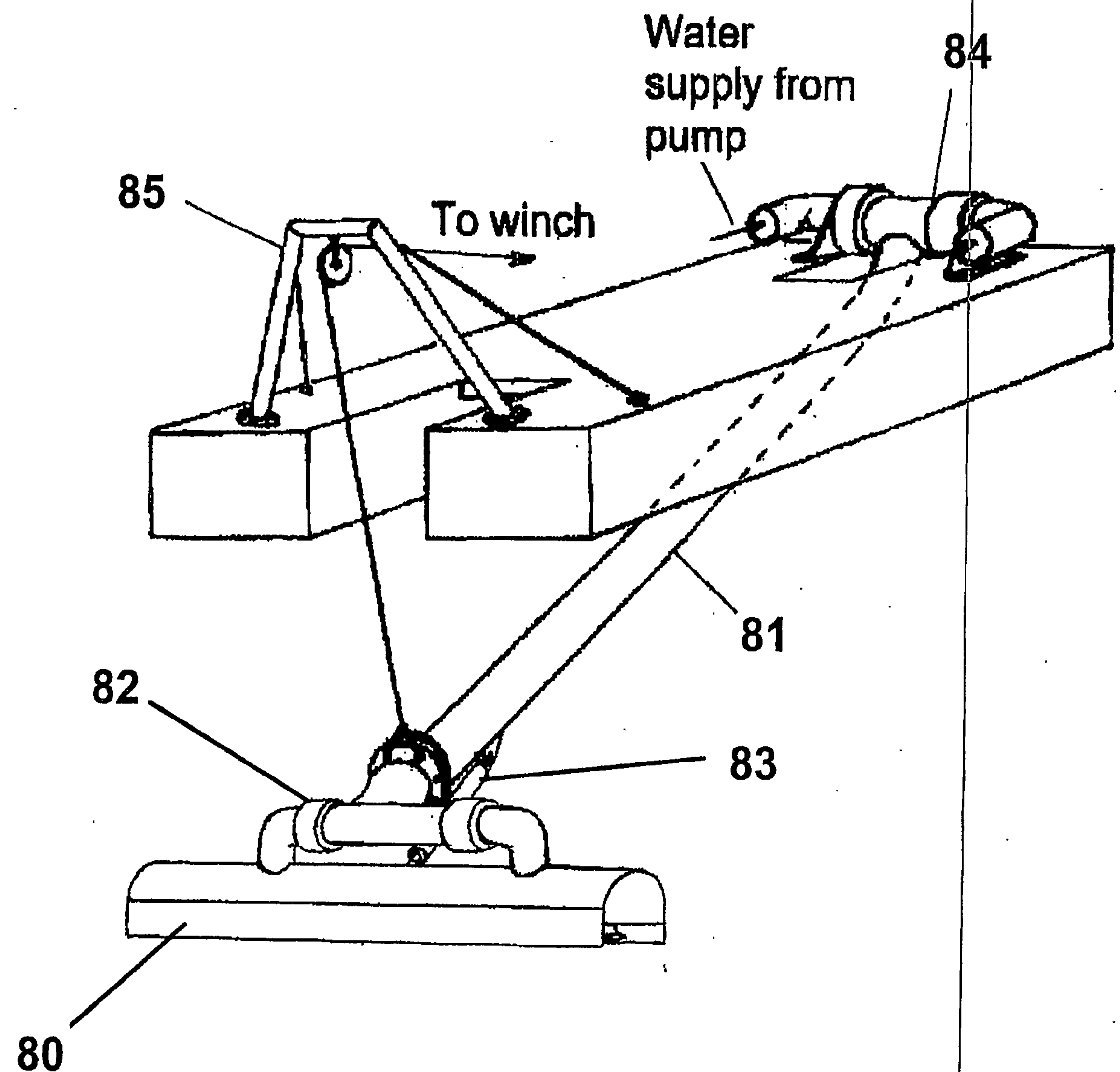



Figure 10b

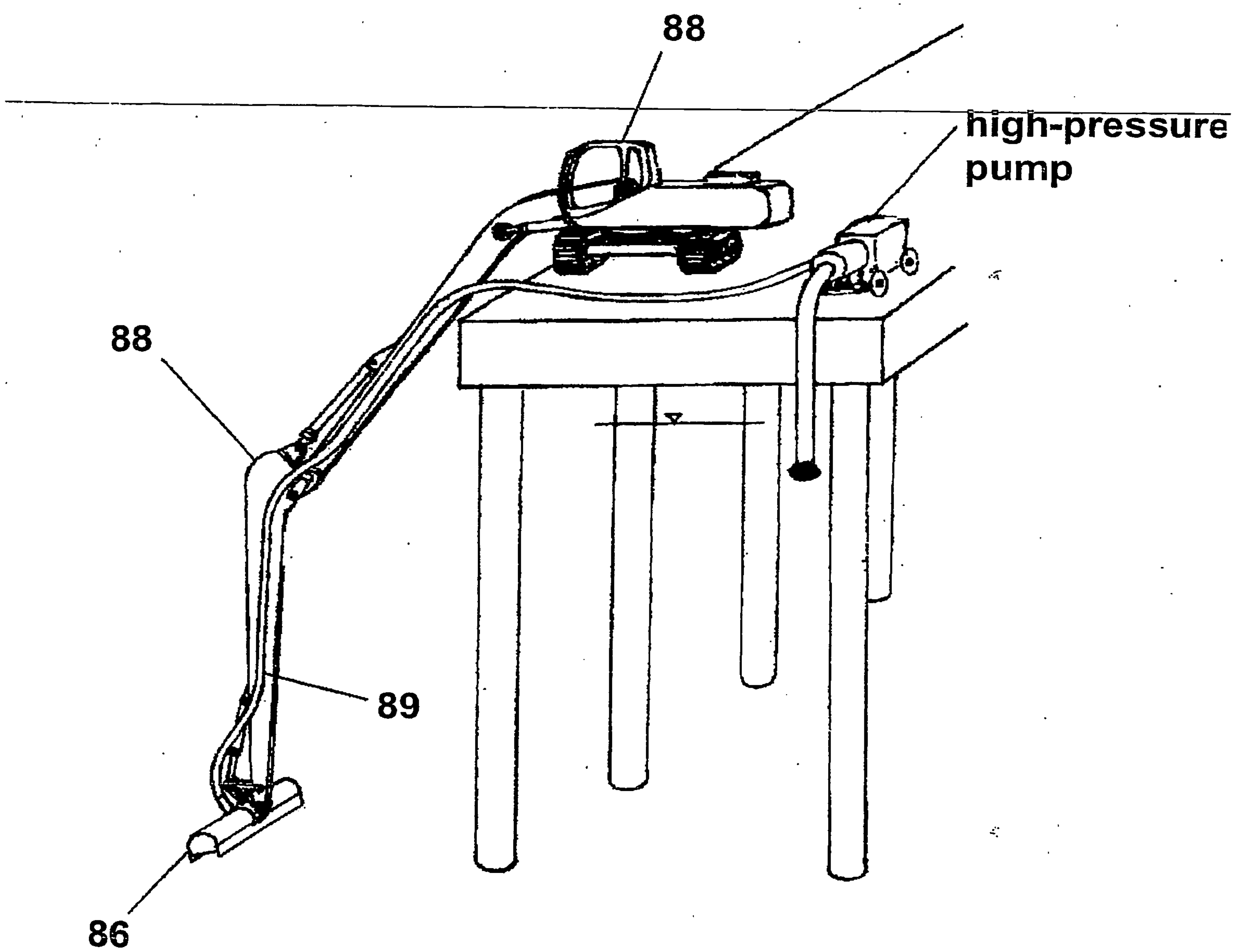



Figure 10c

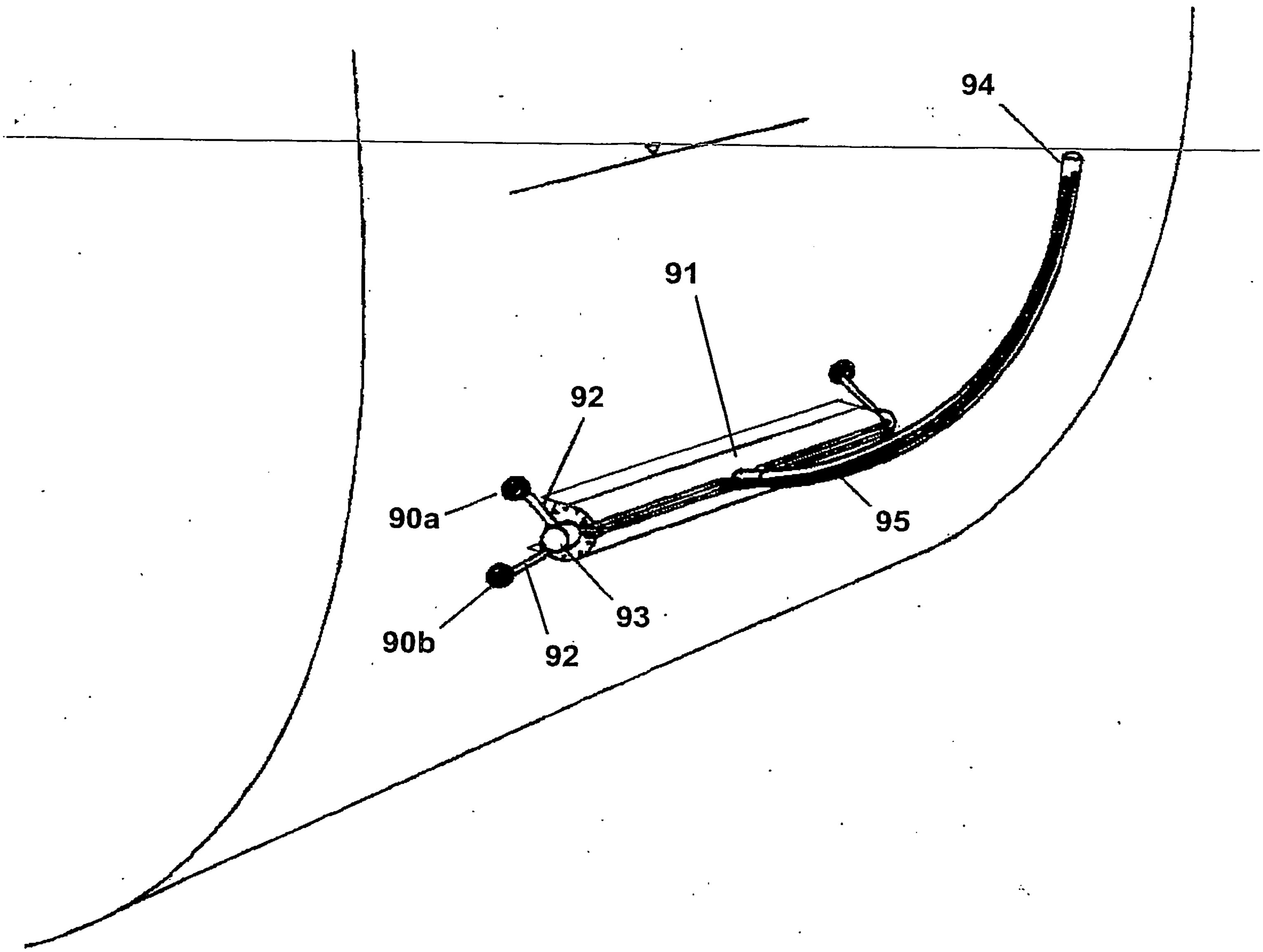



Figure 11

PCT Application
GB0305030